Auburn University
Southern Forest
Nursery Management
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TECHNICAL NOTE 06-01

CHLOROPICRIN - 300 LBS/ACRE UNDER A TARP: AN EFFECTIVE ALTERNATIVE TO METHYL BROMIDE FUMIGATION

by
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Although nursery managers still have the option of using methyl bromide fumigation to increase seed efficiency, the cost is increasing. In 2006 methyl bromide was about $2,100/acre when using gas allocated under the United Nations Critical Use Exemption (CUE). At a few nurseries in Mississippi and Alabama, the cost was about $1,550 if soil was treated to control certain pests under the Quarantine Pre-Shipment (QPS) program. The cost to fumigate with 300 lbs/acre of chloropicrin (under a tarp) was about $1,600 to $1,700/acre (which is cheaper than CUE methyl bromide). In California and Japan, the use of chloropicrin is increasing. In 2003, growers producing strawberries, melons and peppers in California used it as the sole fumigant on 4,000 acres (Trout 2005). In 1999, Japan used twice as much chloropicrin (8,891 tons vs. 4,391 tons) for soil fumigation than methyl bromide (Tateya 2001). The use of chloropicrin (trichloronitromethane) in forest tree nurseries will likely increase as well.

The Southern Forest Nursery Management Cooperative began testing 100% chloropicrin in 1992 (Table 1) and published a literature review a few years later (South et al. 1997). When tarped and used at a rate of 300 lbs/acre, seedling production (i.e. seed efficiency) is generally comparable to that obtained from methyl bromide. In contrast, certain other legal alternative fumigants have (1) been unreliable; (2) stunted or killed adjacent seedlings; (3) produced variable seedlings; and (4) suppressed beneficial *Trichoderma*. This report describes some of the operational considerations when fumigating with 100% chloropicrin.

Table 1. Fumigant trials in loblolly and slash pine seedbeds that included 100% chloropicrin under a tarp.

Year	Nursery	Rate lbs/acre	Season	Plantable seedlings (diff. from untreated)	Reference
	LOBLOLLY PINE			#/sq.ft.	
1992	Statesboro, GA	250	Fall	+1.2	Carey 1995a
1993	Summerville, SC	250	Spring	+1.1	Carey 1995a
1994	Providence Forge, VA	300	Spring	+0.9	Carey 1995b
1994	Washington, NC	300	Fall	+3	Weyerhaeuser #10
1994	Ft. Towson, OK	300	Fall	+10	Weyerhaeuser #7
1994	Winona, MS	250	Spring	-1.2	Carey 1996
1996	Byromville, GA	300	Winter	+1.7	Carey 1998a
1997	Byromville, GA	300	Spring	+4.0	Carey 2000
1998	Atmore, AL	300	Spring	-0.8	Cram et al. 2002
1998	Byromville, GA	300	Spring	-0.5	Cram et al. 2002
1998	DeRidder, LA	250	Spring	+6.0	Carey 2000
1998	Glennville, GA	250	Spring	+2.0	Carey 2000
1998	Bullard, TX	300	Winter	-0.7	Carey 1998b
1999	Chatsworth, GA	300	Spring	-0.2	Cram et al. 2002
2001	Ashburn, GA	300	Spring	--	Carey et al. 2004
2005	Alto, TX	300	Fall	--	--
	SLASH PINE				
1996	Byromville, GA	300	Winter	-0.7	Carey 1998a
1997	Byromville, GA	300	Spring	+2.0	Carey 1998c
1998	Glennville, GA	250	Spring	+4.0	Carey 2000
2001	Glennville, GA	300	Spring	-2.9	Carey et al. 2004

Many other trials include chloropicrin but at lower rates, with no tarp or combined with other compounds.

TARP

To obtain more consistent efficacy, a tarp is required when treating with chloropicrin (Carey et al. 2004). The tarp can heat up the soil and can protect the soil from cold rains (which can delay the degradation of chloropicrin). The tarp should be kept in place for at least 48 hours but it would be preferable to keep it in place for 5 days to maintain a longer treatment period and allow enough time for the chloropicrin to degrade. After 6 days under a tarp, there should be little chloropicrin remaining in the soil (Wang et al. 2006). In contrast, with a water seal, chloropicrin might still be detectable at depths below 1 foot (Wang et al. 2006). Some plastics are permeable and 10 to 20% of the chloropicrin might be emitted into the atmosphere through the tarp (Wang et al. 2005).

With a tarp, treating with 300 lbs/acre might reduce the population of nutsedge plants by 94% but without a tarp the reduction might only by 66% (Carey et al. 2004). At the Byromville Nursery, the use of a tarp greatly increased the soil concentration of chloropicrin in the upper foot of soil (Wang et al. 2006). A tarp minimizes the release of chloropicrin vapors into the air. For the above reasons, managers should consider using a tarp when applying chloropicrin.

RATE

In some nursery trials, chloropicrin rates as low as 125 lbs/acre have been tested (Carey 1995a). However, this rate does not provide consistent results and is not as effective on weed seed as higher rates (Haar et al. 2003). In fact, reports from Florida indicate that low rates of chloropicrin can stimulate the emergence of nutsedge (Motis and Gilreath 2002). For these reasons, mangers should consider applying 300 lbs of chloropicrin under a tarp. After treatment, the soil should be allowed to aerate for 10 to 14 days.

SEASON OF TREATMENT

Chloropicrin can be applied in either the fall (when seedlings are present in adjacent fields) or in the spring (after crops in adjacent fields have been lifted). Most studies have involved spring fumigation (Table 1).

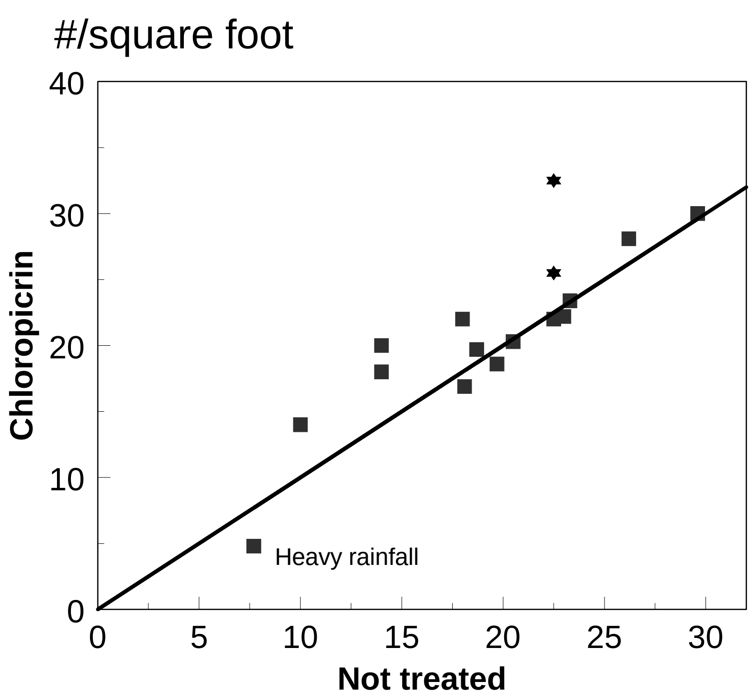

Figure 1. Each dot above the solid line represents a case where more seedlings were counted on plots treated with chloropicrin. Each dot represents a study listed in Table 1.

SEED EFFICIENCY

Two primary reasons nursery managers fumigate soil are to increase seed efficiency and to maintain customer satisfaction. Increasing the number of plantable pine seedlings by just 5% can justify the cost of fumigation (South et al. 1997; South and Enebak 2005). For example, assuming 29,000 square feet of seedbed per treated acre, increasing seedling production by 1.2 seedlings per square foot would increase crop value by $1,740 per acre (at 5 cents per seedling). Under these assumptions, perhaps 58% of the time (11 out of 19 times) we could justify fumigation with chloropicrin (Table 1). This ratio might increase if some managers decide to fumigate only after a severe pest problem occurs.

For years when soil fumigation does not increase crop value, the treatment might be considered as a type of insurance (Hodges 1961). Since we cannot predict when soil pests will reduce crop yield, nursery managers have to weigh the potential risks and benefits of soil fumigation. Those who want to maintain a good reputation of producing uniform, asymptomatic pine seedlings year after year, might decide to fumigate their soil once every four or five years. Examples of where fumigation does not increase seed efficiency can be compared to years when a farmer did not benefit from buying crop insurance.

FUNGICIDE

Overall, chloropicrin is a better fungicide than methyl bromide (Goring 1962). In some cases, half the amount of chloropicrin was just as effective as methyl bromide (Enebak et al. 1990). Chloropicrin is effective in reducing soilborne populations of *Fusarium*, *Rhizoctonia* and *Pythium* spp. (Enebak et al. 1990). In order to provide better control of fungal diseases, chloropicrin is often added to other fumigants.

HERBICIDE

Chloropicrin is a herbicide (Figure 2), but it does not control annual weeds as well as methyl bromide. For example, at a nursery in Mississippi, the percentage of ground covered by weeds 53 days after fumigation was 39% for untreated soil and 6% for soil fumigated with MC-33 (i.e. 155 lbs of methyl bromide plus 80 lbs of chloropicrin per acre). In comparison, soil treated with 250 lbs/acre of tarped chloropicrin had 14% weed cover (Carey 1996). Chloropicrin can kill weed seed of common purslane (*Portulaca oleracea*) and common chickweed (*Stellaria media*) but like methyl bromide, it is ineffective on cutleaf filaree (*Erodium cicutarium*) and cheeseweed mallow (*Malva parviflora*) (Haar et al. 2003). Since windblown seed can quickly populate newly fumigated soil, herbicides should be applied to keep seedbeds relatively free of annual weeds.

Chloropicrin has activity on both yellow nutsedge (*Cyperus esculentus*) and purple nutsedge (*Cyperus rotundus*) (Godfrey 1939; Carey and South 1999; Cram et al. 2002; Carey et al. 2004: Gilreath and Santos 2004). Adding chloropicrin to other fumigants increases the control of yellow nutsedge (Hutchinson et al. 2003). At some nurseries, the amount of emerged nutsedge plants was reduced by more than 80% (Figure 3). Some alternative fumigants have little or no effect on nutsedge populations (Carey 1995a). The effect of chloropicrin on nutsedge at the DeRidder Nursery is illustrated in Figure 4.

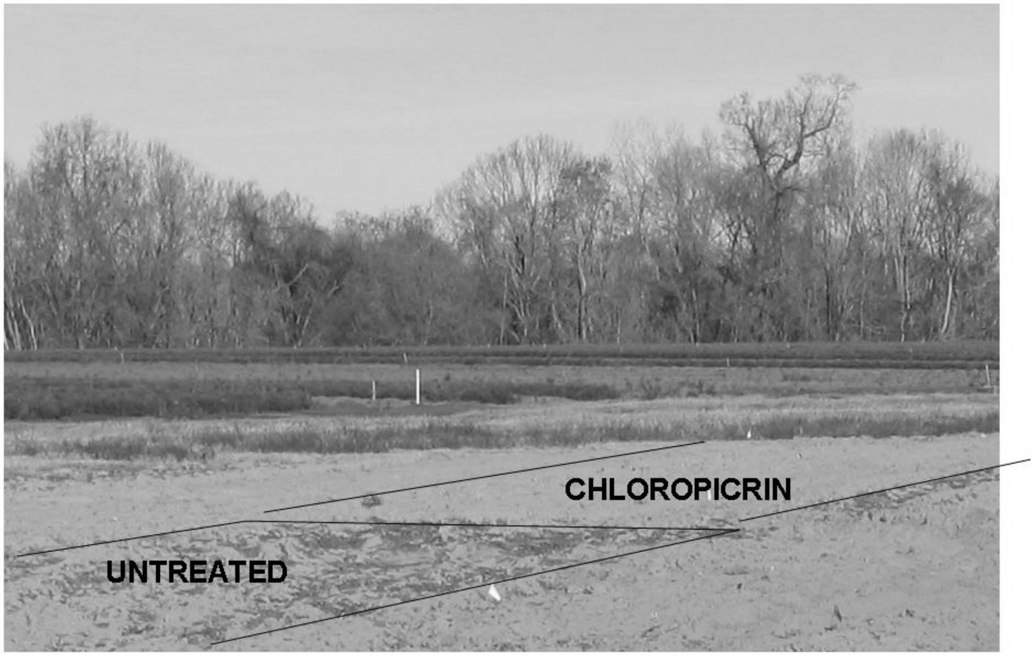

Figure 2. The effect of a fall application of chloropicrin (300 lbs plus a tarp) on the population of annual weeds at the Indian Mound Nursery in 2006.

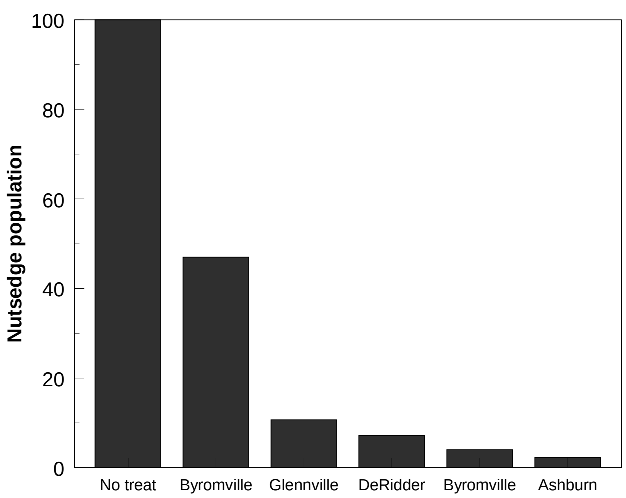

Figure 3. The effect of spring fumigation with chloropicrin on the population of nutsedge at four forest tree nurseries (Carey 1998b; Carey 1999; Cram et al. 2002; Carey et al. 2004)

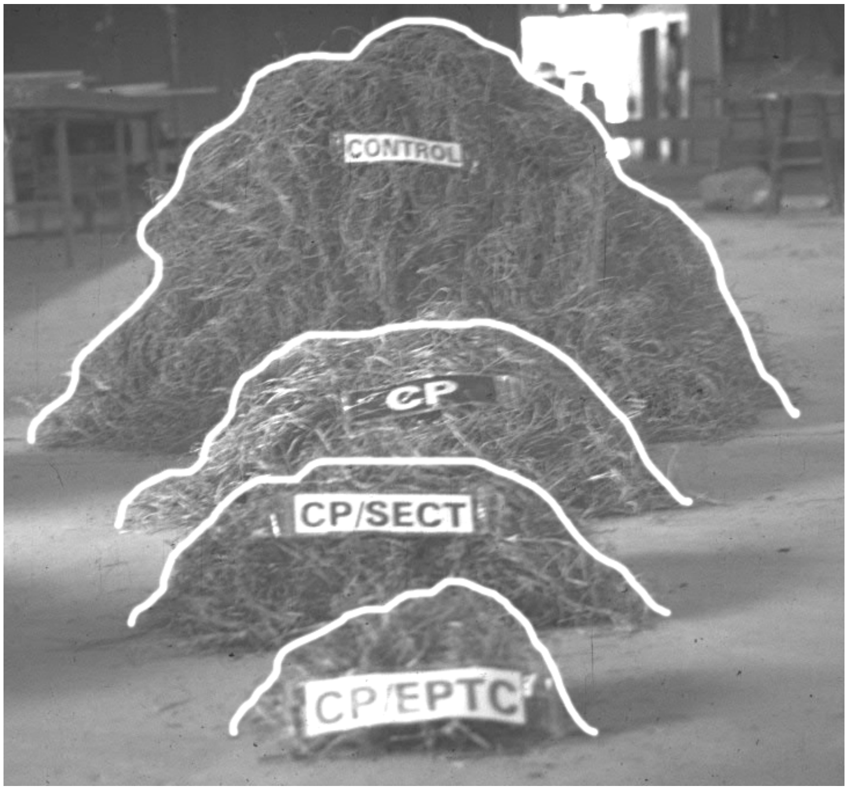

Figure 4. The effect of chloropicrin on nutsedge at the DeRidder Nursery in 1998. There are four piles of plants in this photo. The big pile in the back is from untreated plots; the next pile is chloropicrin at 250 lbs/acre (CP), followed by the chloropicrin plus Sectigone (CP/SECT) treatment. The small pile in the front is from plots treated with 250 lbs/acre of chloropicrin plus EPTC at 6 lbs a.i./acre (CP/EPTC).

NEMATODES

The nematocidal properties of chloropicrin have been known for more than seven decades (Johnson and Godfrey 1932; Godfrey 1935). In some soils it can be effective on nematodes (Trout et al. 2003) and in some cases it can suppress nematode populations when applied at one-third the rate of methyl bromide (Harris 1991). However, chloropicrin might not be as effective on stunt nematodes (*Tylenchorhynchus claytoni*) as methyl bromide (Carey 1998a). When nematodes reside a foot below the fumigation zone, it might not matter which fumigant is used. Certain nematodes can escape below the fumigation zone and can stunt pines during the second year after fumigation (Cram et al. 2003). In some dazomet-treated soils, the population of *Longidorus americanum* at the end of the year might reach pre-fumigation levels (Fraedrich and Dwinell 2005) and the population level might be high enough to stunt the next crop of seedlings. Since chloropicrin can penetrate deeper than one foot (Gan et al. 2000; Wang et al. 2006), new studies need to be installed to determine the effects of chloropicrin on *Longidorus*. In some cases, nematicides are applied prior to sowing (Carey 1998b; Fraedrich and Dwinell 2005) but they typically are not applied after pines have emerged (South and Enebak 2005).

TRICHODERMA

Some alternative fumigants have lowered the population of *Trichoderma* in nursery soils (South et al. 1997; Fraedrich and Dwinell 2003a). In contrast, chloropicrin (with or without methyl bromide) can result in an increase in Trichoderma (South et al. 1997; Carey et al. 2004). For this reason, the use of chloropicrin (under a tarp) can result in a "biocontrol effect" (South et al. 1997). To promote "healthy" soil microflora, nursery managers should consider fumigating with 300 lbs/acre of chloropicrin under a tarp.

ECTOMYCORRHIZA

There have been no reported problems with ectomycorrhizal formation of northern (Enebak et al. 1990) or southern pines after fumigation with 100% chloropicrin. However, all studies to date have been on "old-ground" where ecotomycorrhizal inoculum can be found below the fumigation zone. It is unknown if "new-ground" syndrome (South et al. 1988) will occur when a dry spring follows a chloropicrin+tarp fumigation. The chances of an ectomycorrhizal deficiency are likely to be the same as it was with methyl bromide fumigation.

HARDWOODS

Only a few fumigation trials have been established on hardwood seedbeds. Tests involving chloropicrin have been conducted on sweetgum and oak seedbeds (Carey 2001a; b). At both nurseries, chloropicrin (250 lbs/acre) was applied without a tarp. No fumigants affected sweetgum and in terms of seedling production and seedling biomass, the 250 lbs/acre of chloropicrin was the best for oaks. While conclusions should not be made from just one or two studies, these studies indicate that chloropicrin might be useful for ectomycorrhizal hardwoods.

In the past, we have expressed concern that endomycorrhizal deficiencies might occur when fumigating with chloropicrin (South et al. 1997). Others have said that "chloropicrin used alone at the relatively high dosages of 320-480 lbs/acre does not appear to harm the VA fungi; in some instances it even appears to favor its growth" (Wihelm and Westerlund 1994). Although 200 lbs of chloropicrin (under a tarp, in combination with another fumigant) did not stunt sweetgum (Carey 2001a), no assay was conducted to determine if endomycorrhizal formation was affected. Future research needs to determine if chloropicrin (300 lbs/acre with a tarp) will reduce or enhance the numbers of endomycorrhiza on hardwoods.

ENVIRONMENTAL

Chloropicrin (CCl_3NO_2) undergoes rapid photolysis in the troposphere and is not listed as an ozone depleting compound (Ruzo 2006). In soil, the breakdown products of chloropicrin include carbon dioxide, nitrate and chloride. Chloropicrin breaks down rapidly in comparison to other fumigants (Gan et al. 2000; Spokas et al. 2005) and is not as soluble in water as other fumigants (solubility is about 1.6 g/kg). The half-life in lighted anaerobic aquatic environments can be less than 2 hours (Ruzo 2006) and light greatly enhances degradation (Castro and Belser 1981). In soils, the half-life of chloropicrin is less than 5 days under aerobic conditions (Tamagawa et al. 1985; Wilhelm et al. 1997; Gan et al. 2000; Ruzo 2006). The US Environmental Protection Agency has not established a maximum legal limit in drinking water, but most of the chloropicrin found in tap water is formed as a by-product of water chlorination (Minear and Amy 1996).

MANAGEMENT CONSIDERATIONS

Nursery managers who grow pine can easily adapt to fumigation with chloropicrin under a tarp. They can treat in the fall (when soils are warmer and delays are not critical), or they can fumigate in the spring (assuming the soils are neither too cold nor too wet). The major concern is that nutsedge should be controlled a year or two prior to fumigation with multiple applications of glyphosate on fallow land (Fraedrich et al. 2003). Although chloropicrin can suppress nutsedege, it should not be relied on as the primary tool for nutsedge control.

Many nursery managers have fumigated pines on a 2 pine crop: 2 cover-crop rotation. If nutsedge is controlled with an effective fallow/glyphosate program, a 2:2 rotation can also be used with chloropicrin. However, at nurseries where the nematode *Longidorus americanum* has been a problem, then scouting (e.g. checking of soil samples) should be made to ensure this pest has not built up by the time the first crop is lifted. If it is determined that a field has high populations of this nematode, then some suggest rotating to bare fallow (Cram and Fraedrich 2003) instead of sowing the second crop of pines.

Nursery managers who grow ectomycorrhizal hardwoods will likely fumigate with chloropicrin in the same manner they have with methyl bromide. However, few (if any) trials have been conducted when growing endomycorrhizal species after treating with 300 lbs of chloropicrin (plus a tarp). Problems have occurred in the past when treating endomycorrhizal species with methyl bromide (Riffle 1980; South et al. 1980) and similar problems might occur when using tarped chloropicrin. Small scale trials should be conducted to determine if red maple, yellow poplar and sweetgum will be affected by new fumigants. To provide a margin of safety, diammonium phosphate can be applied (soon after true leaves have formed) to help overcome phosphorus uptake problems that may arise.

CONCLUSIONS

If the production of methyl bromide ceases or if CUE gas becomes cost prohibitive, then many nursery managers will have to adjust their pest management programs. Some managers may choose to fumigate with chloropicrin with a tarp. Other managers may decide to fumigate with alternatives that might be less effective or involve more risk. Others may decide to forgo any fumigation. Those that use 300 lbs of chloropicrin (with a tarp) will be able to adapt with minimal changes in management regime. The biggest change in management will be the need to adopt a vigilant (i.e. year-round) nutsedge elimination program.

In summary, when fumigating with chloropicrin:

- A: Use a plastic tarp
- B: Use a rate of 300 lbs per acre
- C: When possible, leave the tarp down for six days or more
- D: Adopt a year-round nutsedge control program (that includes use of glyphosate on fallow ground).

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