Chloropicrin and Soil Health

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ABSTRACT

Chloropicrin is a soil fumigant that has been used commercially and rigorously studied for more than 100 years. Chloropicrin continues to be a vital tool for the management of soil health in modern agriculture. In addition to reducing the populations of soil pests including pathogenic fungi, nematodes, insects, and weeds, chloropicrin stimulates the proliferation of beneficial soil microbes in the weeks and months following treatment, including *Trichoderma* spp. and root-colonizing pseudomonads. Chloropicrin does not negatively affect the populations of ectomycorrhizae. Following soil fumigation with chloropicrin, the levels of essential plant nutrients are increased by the initial breakdown of soil microflora cells, and a subsequent proliferation of saprophytic organisms in the treated soil occurs due to the phenomenon of competitive exclusion. This article summarizes the scientific literature on chloropicrin and soil health.

Introduction:

Chloropicrin is a widely used soil fumigant throughout the world, with registrations in more than 30 countries, and new countries being added to the list. It is well recognized as an effective soil disinfestation tool critical in high value crops where crop loss due to soil pests can be significant. Because of its documented and favorable effects on soil health, and lack of residues or soil contamination issues, chloropicrin has continued to pass the regulatory hurdles in the U.S., Europe, and globally as a safe and effective pre-plant soil treatment.

This paper is intended to be a reference document and broad overview of chloropicrin, its properties as a soil fumigant, and its impact on soil health. The author will update this document as new research results and/or literature references become available.

Definition of Soil Health:

Soil health is a topic which has gathered a great deal of interest in recent years. However, the term has been used loosely and, oftentimes, in a vague, non-quantitative manner. The author has not discovered an adequate definition of soil health from the scientific literature, nor in trade publications; there simply is no universally accepted definition of "soil health". Therefore, the author has proposed a definition of soil health based on the pragmatic objectives of farmers with regards to soil management, which include growing healthy and profitable crops in a perpetual/sustainable production system, and maintaining or improving the soil microbiological conditions over time.

This proposed definition of soil health is:

The state of soil conditions characterized by 1) Reduced populations of soil pests; 2) The proliferation of microorganisms beneficial to crop health, and; 3) Optimal soil chemical and physical characteristics that support the specific needs of the crop being grown.

All of these three soil components can be measured, and therefore different soils or treatments can be compared. Thus, if we want to compare fumigated vs. non-fumigated soil, or more broadly, treated vs. untreated soil, or one fumigant compared to another, we can establish a set of parameters of soil health that can be quantified, using this definition as a framework.

A measurable, specific definition of soil health permits us to interpret the scientific literature relevant to this topic. This allows us to bring context, meaning, and real world significance to historical research.

And finally, a definition of soil health facilitates our conversations with the greater agriculture industry including regulatory bodies, and our customers, who want to understand the effects that fumigants have on their soil.

History of Chloropicrin:

The earliest report of chloropicrin investigated as a soil disinfestation method was by Russell (1920). Although the paper is written without significant details, it identified chloropicrin as an effective soil disinfestation treatment.

The first published field research with chloropicrin as a soil fumigant was completed by Johnson and Godfrey (1932) at the Hawaii Experiment Station, University of Hawaii. In pineapple fields infested with root knot nematode, they reported “remarkably increased vigor” of pineapple plants, a decrease from 90% to 30 % root infection, and a 57% increase in yield when chloropicrin was injected in the soil at application rates of 83-204 lbs/acre. A greater amount of root growth including fine, feeder roots, and aboveground vegetative growth was noted. Beneficial effects were carried over to the first ratoon crop, one year later. These field studies were conducted from 1927-1932 and the researchers injected chloropicrin 5 to 6 inches deep, spaced 18 inches apart and covered with “mulching paper”. This paper by Johnson and Godfrey represents the first published field trial identifying chloropicrin as a “soil fumigant” and which describes in significant detail successful field applications to suppress a major crop pest.

Newhall (1955) published the first comprehensive review article on soil disinfestation, including detailed descriptions of chloropicrin as a soil fumigant. The summary cited over 280 published research articles from 1920-1955, and discussed the effects on soil microbiology of dry heat, steam heat, hot water, flooding and chemical fumigants including chloropicrin, carbon disulfide, dicloropropene-propane mixture, ethylene dibromide, and formaldehyde. Newhall’s review has meaningful discussions and observations on soil microbiology, and what today would be called soil health. The documentation on chloropicrin is extensive, with many cited works discussing the efficacy of chloropicrin against soil fungal pathogens, weeds, insects, and nematodes. It provides comparisons among the various fumigants of the day, including methyl bromide and dicloropropene. Notably, the Newhall states that chloropicrin was recognized as being “the best fungicidal fumigant” and; “Because of its ability to destroy a great variety of soil pests, chloropicrin was widely employed where crop value was high.”

In the 1940’s and 50’s, as more soil fumigants were developed and marketed, such as formalin, 1,3-dicloropropene/dicloropropane (Carter, 1943, 1945), methyl bromide, isothiocyanate, and ethylene dibromide, the relative pricing of the various fumigants came into play. Markets were competitive. Mixtures of different fumigants also began to be explored. Throughout these years, chloropicrin was widely recognized as being the best fumigant against soil fungal pathogens, being a superb insecticide, having good nematicidal properties, and having significant effects on weed suppression.

Chloropicrin is a proven soil fumigant

The results of many agricultural researchers from the 1930’s onwards established chloropicrin’s efficacy in reducing a broad spectrum of soil pests, including insects, fungi, nematodes, bacteria, and weed seeds (Newhall, 1955). The publications on chloropicrin as a soil fumigant in the scientific literature continued through the ensuing decades and continue to this day. Wilhelm et al. (1974) published a classic paper describing fifteen years of development of methyl bromide-chloropicrin mixtures in the California strawberry industry. The authors discuss the concepts of “soil sickness” and restoring “worn-out” (disease-ridden) soils to productivity. Enfinger et al. (1979) published a study whereby chloropicrin was the only treatment that provided full season control of bacterial wilt in tomato (*Ralstonia solanacerum*). Munnecke and Van Gundy (1979) published an in depth review article on soil fumigants which discusses their comparative chemical diffusion in the soil, their physical properties, effects of soil moisture, texture, and composition, soil sealing, and discusses at length biological factors in the soil. Lembright (1990) wrote a feature article on soil fumigation and application technology. South et al. (1997) described the success with chloropicrin as a soil fumigant in forest nurseries. Wilhelm and Westerlund (1998) published a summary of chloropicrin and discussed its effects on soil pests as well as beneficial organisms, synergism with methyl bromide, and the history of chloropicrin. Noling et al. (2013) wrote a chapter where they presented a discussion of soil fumigant alternatives to methyl bromide in the Florida vegetable industry. Finally, university and extension research continues to be a very active area in agricultural science globally, and new publications on chloropicrin fumigant treatments appear every year. There are now many hundreds, if not several thousands, of efficacy trial reports of chloropicrin scattered over many decades and available in dozens of different scientific journals that represent different global regions, crops, and numerous soil pest complexes.

The addition of chloropicrin to other soil fumigants increases the efficacy over either fumigant alone. This was demonstrated with methyl bromide by, for example, Eneback (1990) in forest nursery production. Chloropicrin use with 1,3-Dicloropropene (1,3-D) is the standard fumigant treatment in the highest value crops in the U.S. including strawberry, tomato, pepper, cucurbits, and perennial tree crops such as almond, walnuts, apples and cherries. These two fumigants (1,3-D and chloropicrin) make an excellent combination, which is more effective than either fumigant alone when multiple pest species threaten a crop. Current research continues to investigate chloropicrin combinations with 1,3-Dicloropropene, dimethyl disulfide (DMDS), and other, exploratory fumigants.

Chloropicrin and soil health

From the early days of soil fumigant development, in the 1930's 40's, and 50's, agricultural researchers were very much aware of biological effects, potential and observed, of soil fumigants. They documented chloropicrin's effect of reducing soil pest damage from pathogens such as *Rhizoctonia* spp., *Pythium* spp., *Phytopthora* spp., *Verticillium* spp., *Sclerotinia* spp., *Fusarium* oxysporum wilt diseases, and bacterial wilt of tomato (*Ralstonia* solanacearum).

Newhall (1955) comprehensively summarizes these early observations on microbiology and soil health in his classic review article on soil disinfestation. His summary statement at the end of the paper states: "Repeated annual fumigations have no deleterious cumulative effects over a five-year period, although temporary suppression of nitrification occurs for a few weeks as it does after steaming, with its attendant accumulation of ammonia."

An increased crop growth response was usually noted following soil fumigation with chloropicrin, as was a temporary inhibition of nitrification with a corresponding increase in ammonia nitrogen in the soil. This increased growth response in crops intrigued scientists, and induced research into soil chemistry and microbiology of soils treated with fumigants. Several studies elucidated that the availability of other plant nutrients such as potassium, phosphorous, and micronutrients such as zinc and magnesium could increase following soil fumigation. This led to the well-supported hypothesis that the microbes killed by the fumigant, would naturally degrade, thus liberating basic elements and minerals in their cells to the soil's chemical microenvironment. As much as 10 kg/Hectare of N is released in the soil by fumigation (Altman and Fitzgerald, 1960). Nira et. Al. (1996) reported an increase in N availability up to 84 days following soil fumigation with chloropicrin.

Thus, a flush of plant nutrients becomes available in the soil solution in the days and weeks following soil fumigation with chloropicrin (which is akin to a time-released fertilizer), in addition to a fundamental change in the biological equilibrium of the soil. Ultimately, chloropicrin helps to mobilize more soil nutrients by intensifying microbial activity and organic decomposition (Schchepetilnikova and Cheremisova, 1942).

Essential facts to consider are that chloropicrin is biodegraded rapidly (nitrate, carbon dioxide, and chloride ions), does not leach, and leaves no residues either in the soil or plant (Wilhelm et.al. 1996). The half-life, or degradation rate of chloropicrin in soil has been extensively studied and typically ranges between 1 to 5 days depending on the soil type, soil moisture, soil temperature, and other abiotic factors that affect microbial activity. Microbial degradation is the primary route through which chloropicrin is converted from an active ingredient to basic compounds that can be utilized by beneficial soil microbes (those involved in nutrient cycling and root growth promotion) and plants (as a direct source of nutrients) alike. One soil organism that has been documented to degrade chloropicrin in the soil is *Pseudomonas* spp. (Dungan and Yates, 2003). Pseudomonads are also well-known plant root growth promoting bacteria.

Competitive exclusion

From the early studies on soil microbiology effects from steam sterilization and soil fumigation with chemicals (Newhall, 1955), research scientists observed that broad shifts in microbial populations occurred after treatment. The sudden flush of nutrients that are released from the cells of dead microbes led to flushes of fast-growing saprophytic organisms exploiting the food source. Researchers found that, for example, beneficial fungi populations, such as *Trichoderma spp.*, recovered faster in soil treated with chloropicrin than with steam. Steam sterilization had a much broader biocidal effect than chloropicrin, and was more detrimental to some key beneficial organisms (Yamamoto,2008). This phenomenon illustrates an important concept in soil microbiology: *competitive exclusion*; whereby an organism exploits the soil environment at the expense of other, competing organisms.

One of the key impacts of chloropicrin on soil health is that *Trichoderma* spp. and other competitive saprophytes return within days or weeks following fumigation, often with visible fungal blooms. This is a key shift in soil microflora because *Trichoderma* spp. have been identified as beneficial soil fungi and root colonizers which exclude or delay the return of plant pathogens (Ohr and Munnecke, 1974; Ohr et.al. 1973).

Impact on populations of soil microflora

Chloropicrin has a positive and measurable impact on soil microbial health due to the proliferation of beneficial soil/plant microbes including the immediate proliferation of *Trichoderma* spp. fungi (South et al., 1997; Mellwaine and Mallone, 1976). *Trichoderma* populations were 4-6 times higher in chloropicrin treated soil compared to non-fumigated soil in Mellwaine and Mallone's study (1976) on ryegrass.

It is important to recognize that chloropicrin does initially depress soil bacteria involved in nitrification (Yamamoto et al., 2008), and this results in an increase in ammonium (NH_4^+) levels in the soil for a few weeks. However, this effect is temporary, and nitrifying bacteria recover to their previous levels, or higher. Fortuitously, by temporarily inhibiting soil nitrification processes through a depression of the nitrifying bacteria populations, the nitrogen liberated from dead microbial cells is unavailable to leaching processes, as opposed to nitrate nitrogen. Thus, as the populations of nitrifying bacterial populations recover, the nitrogen tied up in ammoniacal form is slowly made available to the roots of the subsequently planted crop. Steam sterilization has more severe effects, both initially and for a longer time period, compared to chloropicrin (Yamamoto, 2008).

Soil respiration, as an indicator of total biomass activity, was ultimately found to be stimulated by chloropicrin, after an initial decrease (Naganawa et al., 1989). These results are similar to those reported by Ladd et al. (1975), where bacterial populations increased in chloropicrin fumigated soils compared to non-fumigated soil, after an initial depression. Similarly, Yamamoto et al. (2008) concluded that the microbial biomass recovers faster in a chloropicrin treated soil compared to a steam sterilized soil.

Root-colonizing ectomycorrhizae in Douglas-fir seedlings have been shown to be unaffected in soils treated with chloropicrin (Eneback et al. 1990). Similarly, Massiccotte et al. (1997) found that chloropicrin did not adversely affect the formation of ectomycorrhizae on young Douglas-fir seedlings by naturally occurring fungi.

Current research on chloropicrin and soil health.

The impact of chloropicrin on soil microbiology continues to be an area of active research. DNA testing and other molecular technology is providing new tools that can more precisely and easily identify the populations of soil microorganisms in soil treated with chloropicrin. TriCal, Inc. supports this research with several university researchers in the U.S. New information on soil health will become available in the years to come.

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