

New Mexico Chile Association ♦ Report 33



Evaluations of Chloropicrin Fumigants for Management of Soil-Borne Pathogens in Chile (*Capsicum annuum* L.)



College of Agricultural, Consumer and Environmental Sciences
Cooperative Extension Service • Agricultural Experiment Station

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For more information, contact:
New Mexico Chile Association
Jaye Hawkins, Administrator
P.O. Box 845
Mesilla Park, NM 88047
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Evaluations of Chloropicrin Fumigants for Management of Soil-Borne Pathogens in Chile (*Capsicum annuum* L.)

Stephanie J. Walker, Steve H. Thomas, Mark E. Uchanski¹



Research Summary

The soil fumigants Pic-Clor 60 (60% chloropicrin, 40% Telone), Pic Plus (86% chloropicrin), and TriClor EC (94% chloropicrin) (Hendrix & Dail, Greenville, NC) were evaluated in 2009 to determine their effectiveness in managing soil-borne pathogens of chile (*Capsicum annuum* L.). At site 1, a center pivot-irrigated field, Pic-Clor 60 and Pic Plus were applied at high (120 lb/ac) and low (60 lb/ac) rates by shanking the fumigants into the soil. At site 2, a high rate of TriClor EC (125 lb/ac) formulated for application through drip irrigation was tested. TriClor EC was applied to the entire field except for two five-row sections that were left untreated by disconnecting the drip lines prior to applying the fumigant. Both sites were direct seeded with New Mexican-type green chile approximately one month after fumigant application.

Stand establishment (plants/plot) and vigor (plant height) were measured every two weeks after emergence until thinning. One week before harvest, a wilt disease visual assessment was conducted. At site 1, soil core samples were obtained from the pivot-irrigated field followed by root galling assessment later in the season, to evaluate for root-knot nematode incidence. Marketable green chile fruit were harvested from each site, and fresh weight yields were compared among the different treatments. No differences were observed in stand establishment or plant vigor in either test field. In the pivot-irrigated field, no plant loss due to wilt diseases was observed in either the treated or control plots. Direct soil counts did not reveal root-knot nematodes (RKN); however, galling rates indicated higher RKN populations in the untreated plots versus the treated plots, with the high rate Pic-Clor 60 and Pic Plus showing significantly less galling ($P = 0.05$) compared to the untreated control plots. Fresh weight yields appeared to correspond to the galling rates, with significantly higher yields ($P = 0.10$) in the high rate Pic-Clor 60 (21% higher yield) and the low rate Pic Plus (22% higher yield) plots compared to the untreated control plots. In the drip-irrigated field, substantial losses due to *Verticillium* wilt were observed. Untreated plots averaged 29.7% of the chile plants infected versus 4.5% of the plants in the

¹Respectively, Extension Vegetable Specialist, Department of Extension Plant Sciences; Professor, Department of Entomology, Plant Pathology and Weed Science; and Assistant Professor, Department of Plant and Environmental Sciences, all of New Mexico State University.

treated plots. Corresponding to the reduction in *Verticillium* wilt incidence, marketable yield in the treated plots averaged 32,531 lb/ac compared to the lower 26,502 lb/ac in untreated plots, an approximately 19% yield increase in the fumigated sections of the field.

Introduction

New Mexico is the leading state in chile production (non-bell pepper, *Capsicum annuum*) despite a substantial reduction in acres grown since the peak of 36,000 ac in 1995 (New Mexico Agricultural Statistics, 1995-2008). While labor and economic issues have contributed to this acreage reduction, disease pressure has also been cited as a key factor. Early seedling death from soil-borne fungal pathogens (*Rhizoctonia*, *Pythium*, and *Fusarium* spp.) is a continuing challenge for achieving optimum stand establishment in chile. Fungal pathogens also cause substantial losses later in the season. In particular, chile wilt diseases caused by *Phytophthora capsici* and *Verticillium dahliae* result in substantial yield loss and economic challenges for growers. Southern root-knot nematode (RKN; *Meloidogyne incognita*) is a widespread pathogen of chile, as well as many other crops. In highly infested fields, RKN can kill seedlings outright, although it is more common for growers to experience loss of plant vigor due to their presence (Goldberg, 2001).

Chloropicrin was first registered for use as a broad-spectrum soil fumigant in the United States in 1975, but had been used for nematode control since 1919 (Matthews, 1920). Although the chemical was frequently formulated with methyl bromide (in part because of chloropicrin's effectiveness as a warning agent), the current phasing out of methyl bromide has increased interest in chloropicrin formulations as methyl bromide alternatives. Chloropicrin has been shown to effectively reduce fungal pathogens in many vegetable crops, including tomatoes and potatoes, and can thereby increase yield and quality (Hutchinson, 2005; Sydorovych et al., 2008). While some activity against nematodes has been reported, its effectiveness against weed seeds and rhizomes is limited. Chloropicrin fumigants dissipate quickly under standard application temperatures, so damage to the target crop due to residual chemical in the soil is unlikely.

During the 2009 season, chloropicrin formulations were tested in two separate locations in fields that were direct seeded with New Mexican-type green chile. Pic-Clor 60 is a mixture of chloropicrin (60%) and Telone (40%; 1,3-dichloropropene, a commonly used nematicide). Pic Plus and TriClor EC contain chloropicrin at 86% and 94% respectively, along with proprietary emulsifiers (Hendrix and Dail, Greenville, NC). Site 1, located in Pearce, AZ, was irrigated by overhead pivot sprinklers. Site 2, in Deming, NM, was drip-irrigated. The objective of these tests was to gauge impacts on stand establishment, fungal disease infection rate, and final harvested chile yield in fields treated with Pic-Clor 60 and Pic Plus under overhead pivot irrigation and TriClor EC under drip irrigation.

The two experimental field sites differed in production practices and chemicals applied, so they will be summarized separately.

Site 1 - Pivot-Irrigated Field

Materials and Methods

Ed Curry's field in Pearce, AZ, is a Tubac sandy loam soil. The field had been left fallow the previous year, and before that had been planted in corn. The field is irrigated by overhead, center pivot sprinklers. The field was watered and fertilized according to standard practices for green chile production in Pearce, AZ. A pre-irrigation of the field prior to fumigant application raised the soil moisture to approximately 60% field capacity. The soil temperature at treatment was 60°F. Two different fumigant formulations, Pic-Clor 60 and Pic Plus at high (120 lb/ac) and low (60 lb/ac) rates, were applied and compared to an untreated control treatment. Pic-Clor 60 is a mixture of chloropicrin (60%) and Telone (40%) combined for activity against soil-borne fungal and nematode pathogens. Pic Plus is 86% chloropicrin with emulsifiers that reduce volatilization of the chemical. The fumigant treatments were applied on February 21, 2009, in a randomized complete block experimental design with six replications of each treatment. Fumigants were applied with a tractor from pressurized containers by shanking in the chemicals eight inches below the surface of the soil in the center of the beds and immediately packing the soil on top of the chemical. Untreated plots were also physically shanked and packed, but no chemical was applied. The four-row plots were one hundred feet long, separated by a five-foot untreated buffer between treatments within rows.

The New Mexican-type green chile variety grown was 'Villa 96' (Curry Chile and Seed Co., Pearce, AZ). Seed was planted on March 20, 2009, at a rate of 3 lb/ac; seedling emergence occurred on April 11. Stand establishment (plants/plot) was measured in randomly selected 1-m plots in each of the two inner rows for each replication prior to thinning the field. Seedling vigor was determined by measuring individual seedling height in the 1-m plots on May 28, and then three more times at two-week intervals.

Approximately one week before the field was harvested, a disease assessment was conducted to determine the incidence of wilt disease, and marketable green chile fruit were picked from randomly selected 2-m plots in each treatment area. Fresh samples were weighed to determine total marketable fruit per plant, which was extrapolated to marketable fresh pounds per acre. In addition, shoot biomass was harvested and dried to determine aboveground biomass productivity.

On July 1, at the peak of plant growth, soil cores were taken for nematode evaluation from the plots that had been used for stand establishment and seedling vigor measurements. A total of 15 12-inch cores were taken in each plot by angling the corer into the plant root zone. Following soil extraction, total nematode counts and identification were obtained from NMSU's Nematology Laboratory. An additional RKN evaluation of plant root galling was conducted at the end of the season following harvest. From the plots in which yield and shoot biomass samples were previously collected, root balls were carefully dug up using a shovel to prevent loss of fine roots, and roots were rated on a 1 to 6 scale based on percentage of galling. The galls, which each indicate a successful RKN infection, were rated as 1 = no galls, 2 = a trace of galls, 3 = <25% galled roots, 4 = 25 to 50%, 5 = 51 to 75%, and 6 = >75%.

Table 1. Stand Establishment, Disease and Root-Knot Nematode (RKN) Incidence, and Marketable Yield of New Mexican-Type Green Chile Treated With High and Low Rates of Pic-Clor 60 and Pic Plus Compared to Untreated Control Plots at Site 1 in Pearce, AZ, 2009

Treatment	Rate (lb/ac)	Stand Establishment (avg. no. plants/plot)*	Wilt Disease Incidence (% affected plants)**	RKN Gall Rating	Fresh Marketable Yield (lb/ac)
Pic-Clor 60	120	11.3	0	1.34a***	39,087a
Pic-Clor 60	60	11.5	0	1.48ab	35,545ab
Pic Plus	120	12.0	0	1.37a	38,014ab
Pic Plus	60	11.7	0	1.51ab	39,871a
Untreated	0	12.2	0	1.65b	31,072b
Significance level		ns	ns	P = 0.05	P = 0.10

*Plot size = 2 m

**As determined by wilt symptom visual assessments.

***Numbers in the same column followed by the same letter are not significantly different as determined by Duncan's Multiple Range Test at the P-value specified.

Results

Stand Establishment: No significant differences in stand establishment were observed between the treated and untreated plots (Table 1). By the end of data collection, no differences were observed in seedling vigor (data not presented) between the treated and untreated plots.

Pest and Disease Assessment: Viral diseases were present in the field, but would not have been affected by the fumigant applications and were not quantified. No wilted plants infected with fungal pathogens were observed in the field. Evaluation of the soil core samples from the root zone yielded no RKN juveniles, although several genera of non-plant pathogenic and non-galling nematodes were found. A follow-up evaluation of root galling indicated low levels of RKN infection in all plots, with plots treated with the high rates of Pic-Clor 60 and Pic Plus exhibiting significantly less ($P = 0.05$) galling compared to the untreated plots (Table 1).

Yield: No significant difference in dried shoot biomass was observed. Evaluation of fresh marketable yield showed a significantly lower yield ($P = 0.10$) in the untreated plots (31,072 lb/ac) when compared to the high rate of Pic-Clor 60 (39,087 lb/ac) and the low rate of Pic Plus (39,871 lb/ac) treatments.

Site 2 - Drip-Irrigated Field

Materials and Methods

Zack Penn's field, located in Deming, NM, is a Mimbres silty clay loam soil. The previous crop grown in the field was wheat. The field was drip-irrigated with 10-mil tape embedded with emitters spaced 12 inches apart. A single drip tape was situated 6 inches below the soil surface in the center of each bed. The field was pre-irrigated through the drip lines to obtain adequate soil moisture for seed germination (approximately 80% field capacity) prior to application of the fumigant. The soil temperature at treatment was 60°F.

Table 2. Results of New Mexican-Type Green Chile Production Comparing High Application Rate (125 lb/ac) of Tri-Clor EC Applied Through Drip Irrigation Versus Untreated Control Rows at Site 2 in Deming, NM, 2009

Treatment	Rate (lb/ac)	Stand Establishment (avg. no. plants/plot)*	Wilt Disease Incidence (% affected plants)**	Fresh Marketable Yield (lb/ac)
Tri-Clor EC	125	11.3	4.5	32,531
Untreated	0	11.5	29.7	26,502

*Plot size = 2 m

**As determined by wilt symptom visual assessments.

The test field consisted of 126 rows and was treated on March 13, 2009. Two five-row sections within the field (row numbers 43–47 and 80–84) were left untreated by digging up the drip lines and disconnecting them prior to fumigant application. The rest of the field was treated with Tri-Clor EC at a high rate (125 lb/ac) applied from pressurized containers into the drip irrigation lines. Tri-Clor EC is composed of 94% chloropicrin and 6% proprietary emulsifiers.

The New Mexican-type green chile variety was ‘AZ-1904’ (Curry Chile and Seed Co., Pearce, AZ) and was grown in accordance with standard protocols for the area. Seed was planted on April 13, and seedling emergence occurred on May 1. Stand establishment was measured by counting the plants in randomly selected 1-m plots in six treated and six untreated areas prior to thinning. Seedling vigor was evaluated by measuring the height of each seedling at two-week intervals three times prior to thinning. On September 3, approximately two days before the field was harvested, a disease assessment was conducted to determine the incidence of wilt disease. Randomly selected plots 2 m in length (six treated and six untreated) were evaluated. Total plant counts and counts of wilted plants were recorded for each plot. Based on the assessments of Dr. Natalie Goldberg, Extension Plant Pathologist, and Jason French, Plant Pathology Specialist, *Verticillium* wilt (*V. dahliae*) was the predominant fungal disease in the field. All marketable green chile fruit were picked from the same 12 2-m plots immediately after disease assessment. Marketable fruit remaining on wilted plants were also harvested and included in the yield total. Fresh samples were weighed to determine total marketable fruit per plant, which was extrapolated to marketable fresh pounds per acre. On September 11, plots were examined for presence of RKN by assessing root systems for galling.

Results

Stand Establishment: For the drip-irrigated field, stand establishment was similar in both the untreated and treated plots, with an average plant count of 11.5/m and 11.3/m, respectively (Table 2). Early season plant vigor ratings were also similar in the untreated and treated plots.

Pest and Disease Assessment: Although *Verticillium* infection was observed in the treated area of the field, the infection rate was noticeably reduced compared to the untreated area (Table 2). Untreated plots averaged a 29.7% infection rate versus 4.5% of the plants in the treated plots. No sampling for RKN occurred at site 2, although a random evaluation of root balls for galling at the conclusion of the season indicated no discernable infestation.

Yield: Corresponding to the reduction in Verticillium wilt incidence, marketable yield in the treated plots averaged 32,531 lb/ac compared to the lower 26,502 lb/ac in untreated plots, a difference of approximately 19%.

General Results

No phytotoxicity was observed in any of the treatment plots at either site. Effectiveness against *Phytophthora capsici*, the causative agent of Phytophthora root rot and foliar blight, could not be evaluated due to lack of this disease in either trial location.

Conclusions

The fumigants' failure to affect stand establishment at either test location was surprising because chloropicrin has shown benefits in reducing damping off pathogens in other crops in other parts of the country. However, 2009 was not an optimum year to evaluate stand establishment. In general, damping off incidence in chile was unusually low in the 2009 season (personal observation). Environmental conditions that were not conducive to development of these early season pathogens likely masked any potential benefits of the fumigant applications on stand establishment.

Lack of fungal disease at site 1 prevented assessment of the impact of shank-applied fumigants on *P. capsici* and *V. dahliae* infection. The low levels of RKN present at site 1 were apparently too low and/or too sporadic to be detected through midseason soil core analysis. Most root systems observed were also free of RKN galls, demonstrating that nematode infestation within the field was dispersed in discrete locations, or "spotty." Based on direct rating of the root galling on the chile plants, the low incidence of nematode damage was reduced even further in treated plots, with the high rates of Pic-Clor 60 and Pic Plus showing significant ($P = 0.05$) reductions in galling. The reduction in root galling, and therefore RKN infestation, appears to partially explain observed yield increases in the treated plots. It was notable that a yield difference occurred at all considering the lack of fungal diseases and low levels of RKN damage. This indicates that low levels of "spotty" RKN infestation can significantly affect yield in green chile due to root damage. This finding confirms the serious yield impact to New Mexican-type green chile from even very low levels of RKN in the soil (Thomas, 1995).

Although Verticillium wilt was not completely eliminated in the drip-irrigated field at site 2, the Tri-Clor EC treatment did result in a substantial decrease in infection rate. Significance could not be determined due to the necessary lack of replication in the experimental field. Only the wetted area of soil around the drip line or seed line was treated, so viable inoculum still remained in close proximity to developing root systems. Mixing of untreated soil with treated soil during cultivation or growth of plant roots out of the treatment zone can be expected to result in some level of plant infection. Infection from some pathogens, such as *P. capsici*, may also occur when the surrounding untreated soil is thrown onto the aboveground parts of the plants. An additional study to determine if a broadcast-type application of the fumigants would provide more coverage and increase effectiveness against targeted pathogens would be beneficial.

Although impact on weed populations was not measured in these trials, the Deming grower commented on the minimal control of weeds in the Tri-Chlor EC treatment area. Metam sodium fumigants are known to have more activity against weeds and are currently in use by many green chile growers in drip-irrigated fields. A study to determine the relative overall effectiveness of chloropicrin versus metam sodium for controlling pests and pathogens and enhancing chile production would be beneficial.

This study supports the potential yield benefits from applying fumigant compounds prior to chile establishment. If a field is infested with even low levels of pathogens, fumigants can reduce the level of disease, and the increase in crop yield can more than make up for the initial treatment cost. If pathogens are not present, though, the fumigants are an unnecessary expense; growers must therefore be cognizant of field conditions. However, if chile fields are severely damaged by other factors later in the season, such as hail or viral diseases, the grower may lose any added return from the initial investment in the fumigants. Also, fumigant compounds would not likely provide substantial protection against multicyclic soilborne fungal pathogens, such as *P. capsici*, in furrow-irrigated fields because these organisms are rapidly spread with the irrigation water. For more effective control, input costs would be higher due to the need to apply chemical to more soil area (broadcast application) in a furrow-irrigated system.

Acknowledgments

Our sincere thanks to Jason French and Natalie Goldberg for assistance with the disease assessment at site 2, and to Soum Sanogo for additional laboratory analyses.

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Printed January 2012

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