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# Effects of 1,3-dichloropropene plus chloropicrin on weed seed germination

Xiaoxue Ji [a,c,1], Kang Qiao [a,1], Sa Dong [a,1], Hongyan Wang [b], Xiaoming Xia [a], Kaiyun Wang [a,*]

[a] Department of Plant Protection, Shandong Agricultural University, 61 Daizong Street, Tai'an, Shandong 271018, People's Republic of China
[b] Cotton Research Center, Shandong Academy of Agricultural Sciences, Jinan, Shandong 250100, People's Republic of China
[c] Plant Protection and Inspection Station of Feicheng, Feicheng, Shandong 271600, People's Republic of China

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ABSTRACT

Telone C-35, a commercial formulation of 1,3-dichloropropene (1,3-D) and chloropicrin (CP), is one of the potential replacements to methyl bromide (MB) for soil fumigation. A laboratory dose–response study and two field trials in tomato were conducted to evaluate their weed control efficacy and their effect on tomato yield. Laboratory studies found that the seeds of *Digitaria chinensis* were the most sensitive to soil fumigation with Telone C-35, followed by *Eleusina indica*, *Portulaca oleracea* and *Stellaria media* with the $LC_{50}$ values between 3.35 and 11.68 mg $kg^{-1}$ soil. Field trials revealed that Telone C-35 applied to the field at 327, 243 and 164 L $ha^{-1}$ could suppress the percentage of germination weed seeds while maintaining high tomato marketable yields, with no significant differences between MB + CP and the higher two Telone C-35 rates. The yield data from both seasons indicated that all Telone C-35 treatments had a positive effect on tomato yield; there was a 32%–62% increase the mean marketable tomato yield. Our results indicated that Telone C-35 was an excellent MB alternative and could provide acceptable weed control efficacy. Based on our results, Telone C-35, in combination with other alternatives to MB, is recommended to achieve integrated pest management.



## 1. Introduction

Methyl bromide (MB), a very effective broad-spectrum fumigant, will be totally phased out in production and use in China by 2015 due to its detrimental effects on stratospheric ozone and several other issues including human health (UNEP, 2006). Effective alternatives to MB must control three major areas of potential damage to crop production: weeds, plant parasitic nematodes, and soil-borne pathogens. The withdrawal of MB from use as an agricultural fumigant has prompted a research aimed at finding readily available and economically acceptable alternatives.

Currently, the most promising short-term alternatives to MB are 1,3-dichloropropene (1,3-D) and chloropicrin (CP). 1,3-D has very good pesticidal activity in controlling soil-borne phytoparasitic nematodes and, to some extent, fungal pathogens and weeds (Noling and Becker, 1994; Qiao et al., 2010). CP is generally effective on fungal pests, but less effective on nematodes and weeds than MB (Duniway, 2002). However, the combination of 1,3-D and CP (Telone C-17, C-35 and Inline, Dow Agro Sciences LLC, Indianapolis, IN, USA) could reach an integrated control and match MB's efficacy and cost. A wide range of studies conducted in laboratory and field in various cropping systems have proved their excellent efficacy on nematodes, soil-borne pathogens and weeds (Thomas et al., 2009; Covarellia et al., 2010). Hamill et al. (2008) reported that Telone C-35 at 327 L $ha^{-1}$ in conjunction with virtually impermeable film (VIF) reduced nutsedge densities in tomato crops.

Weed control is an important consideration for any MB replacement. The application of 1,3-D and CP often result in inconsistent weed control (Covarellia et al., 2010; Zasada et al., 2010). Covarellia et al. (2010) reported that 1,3-D controlled not only nematodes as expected, but also the most represented weed, *Portulaca oleracea*. However, more information is about their low efficient on weed control (Duniway, 2002; Zasada et al., 2010). The results of Hanson et al. (2010) exhibited that both 1,3-D and 1,3-D + CP treatments showed some weakness on the pernicious weeds such as yellow nutsedge (*Cyperus esculentus* L.) at the garden rose nursery site. Telone C-35 is a mixture of 1,3-D and CP, but little is known about its efficacy on the weeds control in China.

Each country has its own agricultural history, culture and national conditions, which decide that each country's condition of agriculture has its own characteristics. In China, MB is widely used as a pre-plant soil fumigant against soil-borne pathogens, nematodes and weeds (Mao et al., 2012; Qiao et al., 2012). Moreover, soil fumigation in China is mostly conducted by individual farmer not well-equipped commercial companies, lacking essential

* Corresponding author. Tel./fax: +86 0538 8242345.
*E-mail address:* kywang@sdau.edu.cn (K. Wang).
[1] Authors had the same contributions to this paper.

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application tools and personal protection equipment. Environmental side effects associated with human health and the recent loss of MB as a multipurpose soil fumigant have spurred research into its alternatives.

Due to the constraints of the current productivity of agriculture and economics, many advanced fumigant application methods and much of the equipment needed for application cannot be used in China. As one of the most promising short-term alternatives to MB, Telone C-35 has received much attention in recent years due to its wide applications. Thus, our research, conducted in both laboratory and field, was designed to determine the effects of Telone C-35 on weed control and improvement of tomato yield in Shandong, China.

## 2. Materials and methods

### 2.1. Chemicals

Telone C-35, 63.4% 1,3-D, 34.7% CP, and 1.9% inert ingredients, Dow Agro Sciences LLC, Indianapolis, IN, USA. MB, 98% gas, active ingredient (ai), Lianyungang Dead Sea Bromine compounds Co., Ltd, Jiangsu, China.

### 2.2. Laboratory dose–response study

The response of weed seed to Telone C-35 dosage was tested in the laboratory. Seed of weeds common to tomato production in Shandong, China were selected for study. All seeds were obtained from Shandong, China, field weeds, and were transplanted and grown in a greenhouse. Thirty viable seeds each of *Digitaria chinensis* Hornem., *Eleusina indica* (Linn.) Gaertn., *P. oleracea* L. and *Stellaria media* (L.) Cyrillus were placed in plastic mesh bags (Delnet Applied Extrusion Technologies, Inc., Middletown, DE) cut to 6.5 $cm^2$ in size and heat sealed. Seed samples were placed in 250 mL jars (Bomex, Beijing Glass Group Taizhou Bomex Glass Instrument Factory, Jiangsu, China) containing 150 g soil (dry wt). Soil samples were collected from the top 15 cm in the tomato field in Tai'an city, and were classified as a silt loam, composed of 25% sand, 71% silt and 4% clay, with organic matter content 1.56% and pH 7.2. This silt loam soil was selected for the study because it is a typical soil used for tomato production in Shandong, China. This silt loam soil was autoclaved for 1 h at 121 °C and 1.4 kg $cm^{-2}$ pressure, and then adjusted to 14% (w/w) moisture with deionized water. Percentage soil moisture was selected based on methods described by Zhang et al. (1998). Previous studies indicated that dry seeds of *S. media* and *P. oleracea* were not sensitive to fumigation with CP, but seeds moistened with water were sensitive (Haar et al., 2003). Moist field soil was passed through a 2 mm sieve prior to use. Samples were buried 2.5 cm below the jar top, jars were closed with an air-tight lid and seed was allowed to imbibe for 24 h at room temperature (25 ± 1 °C) (Baskin and Baskin, 2001). Exposure time was selected based on 1,3-D and CP field studies indicating that the maximum concentration of 1,3-D and CP in the soil gaseous phase was reached within 18–24 h (Ajwa et al., 2003; Haar et al., 2003; Ajwa and Trout, 2004). Jars were opened, Telone C-35 was added using a syringe at the bottom and then jars were immediately sealed with a new lid.

Treatments were placed in a random block design, each treatment was replicated four times, and the experiments were repeated four times in the laboratory. Telone C-35 was applied to the soil to achieve final concentrations in the soil of 0, 1.0, 2.0, 5.0, 10, 25, 50, 100, 200, 400 and 800 mg $kg^{-1}$ soil (dry weight). Telone C-35 application rates were based on previous studies and label application directions for this fumigant in the field. Jars were opened under a fume hood after 0, 1.5, 3, 6, 12, 24, 48, 60 and 72 h and allowed to aerate for 12 h. Seed packets were then removed, seeds were sorted by species. The seeds were allowed to imbibe on filter papers (Whatman no. 1) moistened with 1 mL of sterile deionized water in Petri dishes (100 mm diameter, 15 mm high). Then Petri dishes were sealed with parafilm and placed in a germination chamber at 25 °C in dark for 24–48 h. Seeds germination were determined by counting seeds that germinated. Seed germination was calculated according to

$$\text{Seed germination}(\%) = (\text{no. germinated seeds}/\text{no. total seeds}) \times 100 \quad (1)$$

### 2.3. Field trials

Two large-scale trials in tomato fields were conducted in Shandong Agricultural University Gardening Experiment Station, Tai'an city, Shandong, China. The studies were established during Fall 2009 and Spring 2010 in two independent farms, respectively. The farms had been in conventional tomato production for 5 years. The soil at the experimental site was a silt loam, composed of 28% sand, 71% silt and 1% clay, with organic matter content 1.91%, pH 7.1 and bulk density was about 1.2 g $cm^{-3}$. The selected experimental sites had a history of heavy natural weeds infestation. Based on previous soil analysis and crop nutritional requirements, the field received a broadcast application of 245 kg $ha^{-1}$ of 15N-0P-25K as starter fertilizer. Prior to treatment establishment, the plots were harrowed twice before planting bed formation.

Seeds of weeds selected in the laboratory dose–response study were also used in the field study using procedures adapted from Haar et al. (2003). Briefly, fifty seeds of each species were placed in an 8 × 15 $cm^2$ mesh bag. Bags were heat sealed and a strip of flagging tape and a steel washer were attached to aid in relocation. Dormant seed was used to prevent germination before treatment and germination tests indicated that seed was >90% dormant. Approximately 24 h before fumigation samples were buried 5 cm deep at the center of each plot length and 23 cm from the center of each plot width. Sample location was chosen to avoid the shank path during fumigation.

Treatments were placed in a random block design with four replicates. The pre-crop fumigants, 67:33 MB:CP was chisel injected to a depth of 25 cm at the rates of 425 kg $ha^{-1}$, and Telone C-35 at the rates of 327, 243 and 164 L $ha^{-1}$, respectively. Untreated beds were constructed concurrently. No herbicides were used at any time on these beds.

Individual plot consisted of five rows and was laid out in a randomized-block design with five replicates with plot size of 40 $m^2$, and there were about 120 tomato plants per plot. Each plot was irrigated with 1.3 cm of water the day before fumigation to allow for better bedding. Immediately after fumigant application, beds were pressed and covered with 0.038 mm low density polyethylene (LDPE) mulch film.

Six-week-old 'Chaoqun Fenguan $F_1$' tomato seedlings were transplanted into the top of the beds after chemicals application. Raised beds were 1.5 m apart and each contained 20 tomato plants spaced 0.50 m apart in the row. Plants were staked and tied as needed during the season. Ordinary flood irrigation was provided according to the water requirements of the crops. Insecticides and fungicides were applied weekly beginning 3 weeks after treatment (WAT) following current recommended practices.

Seed samples were retrieved 2 WAT. Seed was removed from bags, sorted by species and germination determined as described in the laboratory study. Marketable tomato fruits were harvested twice (12 and 14 WAT), which was a typical practice in north China greenhouse and graded according to current market standards into the extra-large, large and medium categories.