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RESEARCH ARTICLE

Gelatin encapsulation of chloropicrin and 1,3-dichloropropene as fumigants for soilborne diseases in the greenhouse cultivation of cucumber and tomato

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Abstract

Combined use of chloropicrin (Pic) and 1,3-dicloropropene (1,3-D) is as effective as methyl bromide (MB) at controlling soilborne diseases in many trials and commercial uses. However, Pic and 1,3-D are both highly volatile and may pose strong exposure risks to humans and the environment. A gelatin capsule formulation containing Pic and 1,3-D has been developed to reduce exposure risks to workers and bystanders and improved application safety. We conducted two experiments in tomato and cucumber greenhouses located in Beijing and Qingdao, China, to study the efficacy of Pic plus 1,3-D gelatin capsules applied at different dosages and soil depths. Results indicated that both injection and gelatin capsules of Pic plus 1,3-D provided good control of soil nematodes and reduced disease index of Fusarium wilt and root-knot nematode. Plant yield of tomato and cucumber treated with gelatin capsules was similar to MB treatment. Based on our results, gelatin capsules applied at a soil depth of 15 cm provided better control of soilborne diseases and led to higher fruit yield compared to an application depth of 5 cm. In conclusion, a gelatin capsule of Pic plus 1,3-D is a promising and novel formulation, which not only shows good efficacy in controlling soilborne diseases, but also reduces potential exposure risks of fumigants.

Keywords: soil fumigation, chloropicrin, 1,3-dichloropropene, gelatin capsule formulation, efficacy, application depth

1. Introduction

Preplant soil fumigation with methyl bromide (MB) has been widely used for approximately 50 years to control insects, nematodes, weeds, and pathogens in many vegetable, fruit, nut, ornamental, and nursery crops (Ristaino and Thomas 1997; Ruzo 2006). However, in 1992, the Montreal Protocol included MB on the list of substances that deplete the stratospheric ozone layer (MBTOC 2010). In 1997, the Protocol established that the use of this fumigant in agriculture should be phased out in developing countries by 2015, except for quarantine and pre-shipment uses and in critical emergencies (Díaz-Pérez *et al.* 2008). Many chemical alternatives to MB and their combinations have been evaluated in numerous crops and different locations across the globe.

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1,3-Dicloropropene (1,3-D), chloropicrin (Pic), metham sodium, and their combinations are used for controlling root-knot nematodes and soilborne fungi in greenhouse tomatoes (Gilreath 2004; Santos *et al.* 2006), cucumbers (Mao *et al.* 2012, 2014), tobacco, pepper, and strawberry (Csinos *et al.* 2000; Ajwa and Trout 2004; De Cal *et al.* 2004; Li *et al.* 2014) in Italy, USA, Spain, and China.

Combined use of Pic and 1,3-D has been shown to be as effective as MB at controlling soilborne diseases in many trials and commercial applications (Minuto *et al.* 2006; Alfonso Cabrera *et al.* 2011). Pic and 1,3-D are both highly volatile and may pose strong exposure risks to humans and the environment. To minimize the negative effects of Pic and 1,3-D on humans and the environment, a gelatin capsule formulation of these fumigants has been developed. The capsule can reduce exposure risks to workers and bystanders during application, and research has documented that total atmospheric Pic and 1,3-D emissions were reduced due to gelatin capsule treatments compared to liquid injection treatments (Wang *et al.* 2009a, 2010). Application of gelatin capsules is also effective in the field. The Pic gelatin capsule is effective against soilborne pathogens in strawberry production (Yan *et al.* 2012), and the 1,3-D gelatin capsule provided good efficacy against soilborne fungi and nematodes (Wang *et al.* 2009b).

In our study, a gelatin capsule formulation of 1,3-D plus Pic was developed to provide a safer and more efficient method of fumigant application as well as effective control of soilborne pathogens. The objective of our study was to determine the efficacy of a 1,3-D plus Pic gelatin capsule towards soilborne pathogens of cucumbers and tomatoes at different application dosages and soil depths.

2. Materials and methods

2.1. Site description and experimental design

Two field experiments were conducted in cucumber and tomato greenhouses located in Beijing and Qingdao, China in 2009 and 2010. Basic physical and chemical properties of soil at the experimental sites are summarized in Table 1. Tomato and cucumber had been grown in these greenhouses for more than 5 years, and the main soilborne diseases in the greenhouses were caused by *Fusarium oxysporum*, *Phytophthora* spp., and root-knot nematode (*Meloidogyne* spp.).

Table 2 provides a list of the treatments tested. Each plot area was arranged using a randomized block design, and each treatment was repeated three times. Pic plus 1,3-D gelatin capsules were produced on a common capsule machine by Dow AgroSciences (US) and the weight percentage of 1,3-D and Pic were 61 and 32%, respectively. The gelatin capsules were applied to field soil by forming holes and inserting one gelatin capsule per hole, without any special application tools. Liquid 1,3-D and Pic were provided by Hunan Yueyang Yunxi Daorenji Solvent Chemical Factory

Table 1 Physical and chemical properties of soil at the experimental sites

Experiment sites	Soil texture type	Clay (%)	Silt (%)	Sand (%)	Organic matter (g kg^{-1})[1)]	pH (soil to water) 1:2.5	Bulk density (g cm^{-3})	Soil moisture (%)
Trial I, Beijing, China	Silt loam	16.3	60.6	23.1	26.69	7.49	1.03	18.5
Trial II, Qingdao, China	Sandy loam	4.0	47.9	48.1	30.79	6.06	1.14	24.2

Table 2 Fumigants used, rates and application methods used in trials in Beijing and Qingdao, China

Fumigant and formulation[1)]	Percent a.i. (%)[2)]	Rate (g m^{-2})	Application depth (cm)	Application method[3)]	Abbreviation of treatment
1,3-D+Pic liquid	62+38	14.5	15	Injection	1,3-D/Pic inj 14.5
1,3-D+Pic liquid	62+38	29.0	15		1,3-D/Pic inj 29
1,3-D+Pic gel cap	61+32	14.5	5	Insertion	1,3-D/Pic cap 14.5/5
1,3-D+Pic gel cap	61+32	29.0	5		1,3-D/Pic cap 29/5
1,3-D+Pic gel cap	61+32	43.5	5		1,3-D/Pic cap 43.5/5
1,3-D+Pic gel cap	61+32	14.5	15		1,3-D/Pic cap 14.5/15
1,3-D+Pic gel cap	61+32	29.0	15		1,3-D/Pic cap 29/15
1,3-D+Pic gel cap	61+32	43.5	15		1,3-D/Pic cap 43.5/15
MB	99	50.0	–	Hot gas	MB 50
Untreated control	–		–		

[1)] 1,3-D, 1,3-dichloropropene; Pic, chloropicrin; gel cap, gelatin capsule; MB, methyl bromide.
[2)] a.i., active ingredient.
[3)] Injection, the fumigant was injected into soil using manual injection equipment; insertion, gelatin capsules containing the fumigant were manually inserted into the soil; hot gas, liquid methyl bromide (from pressurized cylinders) was vaporized in a heat exchanger and then dispersed under plastic film *via* a plastic tube perforated with microholes.
–, not applicable.