Low temperature/ short duration steaming as a sustainable method of soil disinfection

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ABSTRACT

Soil samples containing resting structures of fungal crop pathogens (*Verticillium dahliae*, *Sclerotinia sclerotiorum*, *Sclerotium cepivorum*, *Pythium ultimum*), potato cyst nematodes (*Globodera rostochiensis* and *Globodera pallida*) and weeds (*Chenopodium album* and *Agropyron repens*) were treated with aerated steam in the laboratory at temperatures ranging from 50–80^{o}C in a specially constructed apparatus. Steaming at 50 or 60^{o}C for three minutes, followed by an eight-minute resting period in the steamed soil and immediate removal from the soil thereafter, resulted in 100% kill of all weeds, fungi and nematodes. Low temperature/ short duration soil steaming could become a sustainable alternative to chemical or high-temperature steam soil disinfestation.

Keywords: soil disinfection, aerated steam, methyl bromide, soil-borne pests and diseases, weeds, solarization

INTRODUCTION

Increasing concern about the widespread use of pesticides in crops has created an urgent need to develop new, more environmental friendly crop protection strategies. The use of soil fumigation in particular is based on highly toxic substances, which not only destroy soil-borne pests and diseases but also kill much of the saprophytic and beneficial microflora (Chen, 1991, Gamliel, 2000). Methyl bromide is a very poisonous but widely used soil fumigant that, because of its ozone-depleting properties, is being phased out by 2005 in industrialised countries and by 2015 in developing countries (UNEP, 1998). Worldwide research is currently underway to find replacements for this compound (UNEP, 1998; UNEP, 2000).
Steaming has been used for more than a century as a highly effective way of soil disinfection (Baker, 1962) and is under certain conditions a permitted practice in organic husbandry (Lampkin, 1998). However, the high temperature steam treatments (100-140^{o}C) currently used in horticultural practice have a range of negative side effects, in particular phytotoxicity caused by manganese and/or ammonium release from the soil as well as the creation of an 'ecological vacuum' due to eradication of most of the soil microflora (IKT-AT, 1992). Low-temperature steam-treatments (60-80^{o}C) are thought to avoid many of these negative impacts, but there is little information on the efficacy of low-temperature steam soil disinfection. We selected eight major soil-borne pests, diseases and weeds: fungal pathogens *Verticillium dahliae* (wilt disease), *Sclerotinia sclerotiorum* (white mould), *Sclerotium cepivorum* (onion white rot), *Pythium ultimum* (damping-off); potato cyst nematodes

Globodera rostochiensis and *Globodera pallida* (eel worm) and weeds *Chenopodium album* (fat hen) and *Agropyron repens* (couch grass). Agricultural soil samples containing resting structures of these organisms were exposed to aerated steam at a range of temperatures in a specially designed laboratory apparatus.

MATERIAL AND METHODS

Soils

Two contrasting field soils were used in experiments, i) soil D, a well structured loamy sand, organic matter (OM) 6%, available water (AW) 10-28% and ii) soil W an un-stable, hard-setting, sandy clay loam, OM 1.6%, AW 7-13%.

Inserting target organisms in soil samples

The resting structures of *S. sclerotinia* and *S. cepivorum* (sclerotia), *V. dahlia* (microsclerotia), *Globodera rostochiensis* and *G. pallida* (cysts) and *C. album* (seeds) were inserted in small mesh bags. Soil sample holders, made of steel cylinders with an open top and steel mesh base, contained 1 litre of soil, at a depth of 10 cm. Mesh bags and loose rhizomes of *A. repens* were placed in the middle of the soil samples. One litre of *P. ultimum* inoculated soil was also placed in sample holders.

Moisture content of soil and target organisms

Soils were steamed at moisture level of approximately 70% field capacity, which was also the moisture content of *P. ultimum* inoculated samples. Organisms in mesh bags were tested in a dry and imbibed state. Imbibed organisms were soaked overnight. *A. repens* rhizomes were tested after overnight storage in moist soil. *C. album* and *S. sclerotiorum* were additionally tested after soil moisture equilibration.

Steaming in steam-apparatus

Soil samples containing target organisms were inserted in sample holders and steam-treated in a steel test-rig, measuring ca. 2 x 0.3 x 0.3 m. Four sample holders were placed in a drawer and inserted in the central part of the apparatus. Water was heated electrically in a 50-litre tank. When at the required temperature fine water droplets were mixed with a stream of air (aerated steam) and directed towards the samples, which were steamed from the base upwards. Thermocouples interfaced with a computer and were inserted in the soil amongst the organisms. This enabled temperature readings during steaming procedure. Organisms were steamed at 50, 60, 65, 70 and 80^{o}C. Steaming lasted 3 minutes, after which soil samples were left inside the test-rig for an additional 7 minutes. The drawer was then withdrawn and the organisms removed for further assessment.

Assessment of organisms

Sclerotia of *S.sclerotiorum* and *S. cepivorum* were grown on PDA (potato dextrose agar). *V. dahliae* microsclerotia were plated out on a selective nutrient agar. Seeds of *C. album* were placed on moist filter paper and *A. repens* rhizomes were planted in a sandy compost. Germination / growth of these organisms was established after 14 d. Cysts (*G. rostochiensis* and *G. pallida*) were immersed in potato root diffusate, obtained from roots of potato plants (cv Désirée). They were incubated for 4 weeks,

after which hatched juveniles were microscopically counted. Peas (cv Kelvedon Wonder) were grown in *P. ultimum* infected soil and germination counted after 14 d.

Data assessment

Each test involved four replicates of each organism. The numbers per replicate were: 20 seeds (*C. album*), 16 rhizome nodes (*A. repens*), 30 sclerotia (S*. cepivorum*), 20 sclerotia (*S. sclerotiorum*), 30 microsclerotia (*V. dahliae*) and 10 cysts (*G. pallida* and *G. rostochiensis*). The pea-bioassay was based on four separate *P. ultimum* inoculated soil samples. Control treatments consisted of the same number of organisms and replicates.

RESULTS

Some dry organisms required temperatures up to 80°C to be completely killed but all organisms in a moist state were killed at 50 or 60°C (Table 1). Temperatures were considered lethal when germination/hatching/growth was zero. Average control growth rates were: *C. album*, 74%±3%; *S. sclerotiorum* 100%; *S. cepivorum* 71%± 5%; *V. dahliae* 85%±5%; peas 72%±7%; *G. pallida* and *G. rostochiensis* 57±8 and 159±26 juveniles per cyst respective and *A. repens* 6±0.2 shoots.

Table 1 Minimum lethal steam temperatures of eight major soil-borne pathogens, pests and weeds. Organisms were steamed in two field soils at ca. 70% field capacity. Steaming lasted 3 minutes, followed by an 8-min 'resting' period before removal of organisms from the soil.

Soil-borne pathogens, pests and weeds	Minimum lethal temperatures					
	Soil D			Soil W		
	dry[1]	**imb[2]**	**s.m.e.[3]**	**dry[1]**	**imb[2]**	**s. m.e.[3]**
S. cepivorum	50°C	50°C	nd	50°C	50°C	nd
V .dahliae	50°C	50°C	nd	50°C	50°C	nd
G. pallida	50°C	50°C	nd	50°C	50°C	nd
G. rostochiensis	50°C	60°C	nd	50°C	50°C	nd
C. album	65°C	60°C	60°C	65°C	60°C	60°C
S. sclerotiorum	80°C	60°C	60°C	70°C	50°C	50°C
A. repens.	nd	nd	60°C	nd	nd	60°C
P. ultimum	nd	nd	60°C	nd	nd	60°C

[1] dry = (air) dry organism [2] imb = imbibed organisms [3] s.m.e. = soil moisture equilibrated organism

DISCUSSION

It has been known for a long time that exposure to steam at 60°C for 30 min destroys most soil-borne pests and diseases and reduces problems of phytotoxicity and re-infestation that may occur after steaming at higher temperatures (Baker, 1962; Dawson *et al.*, 1965). For this reason soil pasteurisation (70°C, 30 min) is the recommended method for steam disinfestation of glasshouse soils (IKC-AT, 1992). Despite this, steam practices such as sheet steaming, which tend to last much longer (6-7 h) and result in temperatures of 100°C in the top 25-cm of soil, are commonly used (IKC-AT, 1992). Also, because of the high costs involved, steam treatment is currently limited to a few high value horticultural and floricultural crops. However, our findings suggest that, because major soil pests, pathogens and weeds are killed in steamed soil after only 10 minutes at 50-60°C, a smaller amount of energy may be needed to achieve soil disinfestation and costs of steaming soils could be reduced. Many soil borne pests, diseases and weeds have been controlled in Southern European and Mediterranean countries with low-temperature (45-60°C) 'steam' soil

treatment, based on soil solarization (Katan and DeVay, 1991), apparently with little negative effect on chemical, physical or microbial soil properties (Chen *et al.*, 1991). This relatively new disinfestation technique has been recognised as a non-chemical alternative to methyl bromide (UNEP, 1998) and is used by organic growers (Grinstein and Ausher, 1991; Bell and Laemmlen, 1991; UNEP, 2000). Solarization is however mainly suited to warmer climates. Low-temperature-short duration steam treatment of soil could become a comparable disinfestation method in cooler climates. Further investigations into soil properties with relation to steaming such as matric potential, nutrient content and microbial life are currently in progress.

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