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The effect of soil solarization and fumigation on pests and yields in greenhouse tomatoes

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ABSTRACT

The phasing out of methyl bromide as a fumigant has prompted a search for possible alternatives. Here, the relative efficacy of soil solarization and fumigation with chloropicrin and 1,3-dichloropropene (CP+1,3-D) was evaluated in greenhouse-grown tomatoes. Experiments were conducted over two seasons in southern Italy, aimed at evaluating the effects of soil treatment on soil-borne pest control, and the vegetative growth and fruit production of tomato. Solarization provided a better level of control over the major fungal pathogens (*Fusarium oxysporum* f. sp. *lycopersici* and f. sp. *radicis lycopersici*, as well as *Pyrenochaeta lycopersici*) than CP+1,3-D fumigation. Solarization was also more effective in reducing the population of *Meloidogyne* spp. in the soil, and was particularly valuable for the suppression of the parasitic plant branched broomrape *Phelipanche ramosa* (syn. *Orobanche ramosa*). In both seasons, solarization was more beneficial than CP+1,3-D fumigation in terms of plant growth and crop productivity. In conclusion, solarization provided a good level of control over some important tomato pests and weeds, while at the same time improving the productivity in an environmentally friendly manner. It should therefore represent a viable alternative to methyl bromide fumigation for the greenhouse production of tomato.

1. Introduction

Methyl bromide (MB) has been widely used as a broad-spectrum soil fumigant over a long period, but is now gradually being withdrawn for health and safety reasons. Various techniques have been proposed to replace MB as a means of controlling soil-borne diseases, nematodes and weeds. The leading candidates have been other chemicals, specifically chloropicrin, 1,3-dicholopropene, dazomet and metham sodium. A drawback of any chemical-based soil treatment is that it indiscriminately targets both beneficial and harmful biota, creating a potential biological vacuum typically later filled by pathogens (Gamliel et al., 2000) and producing an end-result worse than that before. Where the climate allows it, an attractive non-chemical alternative is presented by solarization, a treatment which consists of covering a wet soil with a thin transparent plastic film during the hot season. The resulting capture of solar energy raises the soil temperature sufficiently to kill many invertebrate pests, weed seeds and microbes (Mauromicale et al., 2005). Solarization is less liable to create a biological vacuum, and furthermore, appears to stimulate root growth and crop yield (Gamliel et al., 2000; Mauromicale et al., 2005). Finally, it leaves no toxic residue in the soil.

Tomato is the leading field and greenhouse vegetable crop of the coastal zone within the Mediterranean Basin (Tognoni and Serra, 2003). Conventionally, pathogen, insect and weed management, especially in the greenhouse context, has relied heavily on soil fumigation with MB. The favoured replacement for MB is chloropicrin (CP) combined with 1,3-dichloropropene (1,3-D); while CP provides effective control against *Fusarium oxysporum* f.sp. *lycopersici* and f.sp. *radicis lycopersici*, *Verticillium dahliae* and *Pyrenochaeta lycopersici* (Locascio et al., 1997), 1,3-D is a potent nematicide which also shows some fungicidal activity (Duniway, 2002). This combination of pesticides can only represent a short-term alternative to MB, since both of its components are toxic, and thus may in future be phased out, just as MB is being currently. Therefore, there is an urgent need to identify alternative techniques for pest control in tomato production. In several Mediterranean countries, an efficient alternative is soil solarization (Mauromicale et al., 2010; Minuto et al., 2000). This has proven to have a long term effectiveness in controlling soil-borne diseases in tomato (Scopa et al., 2009; Stevens et al., 2003), as well as it ensures good productive and qualitative performances. The literature features only a single comparison of the effectiveness of solarization and fumigation on fresh market tomato production (Chellemi and

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Mirusso, 2001), while the issue of greenhouse production has not been systematically studied. Our objective was to compare the outcomes of solarization and CP+1,3-D fumigation on: (i) the control of soil-borne pests and the parasitic weed *Phelipanche ramosa* (L.) Pomel (syn. *Orobanche ramosa* L.) (branched broomrape), (ii) the plant growth, (iii) the total fruit yield and its components and (iv) the rate of fruit production during the harvest time of greenhouse tomato.

2. Materials and methods

2.1. Site, soil and climate

Greenhouse experiments were conducted during the 2007/2008 and 2008/2009 seasons (hereafter referred as "season I" and "season II", respectively) on the coastal plain of Siracusa (37° 03′ N, 15° 18′ E, 10 m a.s.l.) in a moderately deep calcixerollic xerochrepts soil (USDA, 1975). Prior to treatment, the soil characteristics were: clay 15%, silt 28%, sand 57%, pH 7.6, organic matter 2.0%, total nitrogen 0.1%, available P_2O_5 90 ppm, exchangeable K_2O 650 ppm. The experimental field was covered with plastic films and used for greenhouse tomato production since the last nine years. The experimental area is naturally infested by *F. oxysporum* f.sp. *lycopersici* and f.sp. *radicis lycopersici*, *P. lycopersici*, various *Meloidogyne* spp. and branched broomrape. The local climate is semi-arid Mediterranean, with mild winters and hot, dry summers. The mean 40 year maximum monthly temperatures over the summer months are 29.6 °C (June), 32.5 °C (July), 31.6 °C (August) and 27.3 °C (September) (Servizio idrografico, 1959–1998).

2.2. Experimental design and soil treatments

In both seasons I and II, the experiments were arranged as a randomized block design, with three replications per treatment, based on a plot size of 3m x 15m. Three soil treatments were applied: solarization, fumigation with CP+1,3-D and a no treatment control.

In June all the experimental plots were prepared for the following soil treatments. For the soil used for solarization, 0.70 kg m^{-2} of Organor® (SCAM s.r.l., Modena, Italy), composed of sterile cattle and chicken manure plus roasted leather, was incorporated, since the combination of solarization and organic supplements has been shown to produce a more effective level of control over nematodes than can solarization on its own (Oka et al., 2007). Then, the soils were ploughed several times to provide an uniform surface, levelled and, finally, fertilized. A fertilizer dressing of 15 g N, 24 g P_2O_5 and 36 g K_2O per m^2 was also given prior to the solarization treatment, which was achieved by covering the bare soil, previously irrigated to field capacity up to a depth of 30 cm, with a 20 μm transparent polyethylene film, transmitting more than 91% of visible light and excluding more than 40% of infra-red. The sheets were stretched close to the soil surface and then anchored. The soil was covered from 8 July to 29 August in season I and from 12 July to 31 August in season II. Then, the sheets were carefully removed, avoiding any disturbance to the soils.

The CP+1,3-D fumigation treatment was applied 20 days before planting. The soil was covered by a VIF (virtually impermeable film) (Ecopic®, Agriplast, Vittoria, Italy) with a permeability to CP of less than 0.2 g m^{-2} h^{-1}. A solution of CP+1,3-D (both compounds at 94% w/w) was drip irrigated to give a dose of 30 g CP and 25 g 1,3-D per m^2 according to the manufacturer's instructions. At least two weeks after the fumigation, holes were cut in the VIF to allow the fumigant to disperse.

An uncovered and non-fumigated control was also included in both seasons. The greenhouse, with a steel tubular structure and lateral windows along the sides, was covered with 200 μm ethylene vinyl acetate film, allowing more than 86% of visible light to be transmitted. In both seasons, the greenhouse was covered after soil treatments, as is usual in the area.

2.3. Plant material and management practices

Five week old tomato seedlings (cv. "Parsifal F_1" in season I and "Ikram F_1" in season II) were manually transplanted (season I: 1 September, season II: 25 September). "Ikram F_1" is a late-maturing type which produces fruits optimally harvested as clusters, whereas "Parsifal F_1" is an early-maturing cultivar harvested as single fruits. Both cultivars were grafted onto a "Beaufort" rootstock, which provides resistance to *F. oxysporum* f.sp. *radicis lycopersici*, *Dydimella lycopersici* and tobacco mosaic virus, and tolerance to *P. lycopersici*, *Verticillium* spp. and most *Meloiodogyne* spp. (although not *M. hapla*). Plants were spaced 40 cm apart in rows separated by 1.15 m. Lateral shoots were manually removed to obtain a twin stem structure which could be readily trained on wire. In both seasons, a post-planting fertilizer dressing (20 g N, 8 g P_2O_5 and 31 g K_2O per m^2) was given, and drip irrigation was supplied when the accumulated daily evaporation reached 25 mm (100% of maximum evapotranspiration, ETP). Crop management followed standard commercial practices. Bumblebees (*Bombus terrestris*) were introduced into the greenhouse to encourage cross-pollination. No additional heat, light or CO_2 were provided.

2.4. Evaluation of soil-borne pathogens, nematodes and branched broomrape infestation

During both seasons, disease occurrence was evaluated on a monthly basis by identifying plants showing signs of wilting or developing leaf lesions or darkening. The procedures described by Minuto et al. (2006) were applied to identify the pathogen(s) responsible. Nematode infestation was scored according to a root knot galling index (Di Vito et al., 1979), where a score of 0 reflected the absence of any gall, 1 the development of 1-5 small galls in one region of the root system, 2 no more than 20 galls spread across the root system, 3 a moderate attack with many small galls across the whole root system, 4 a severe attack with large galls reducing the size of the root system and 5 a severe infestation which compromised the root system. The index was determined from six plants per plot at 201 and 231 days after planting (DAP) and at the end of the cropping season. The level of branched broomrape infestation was evaluated by counting the number of emerging main branches (hereafter referred to as 'shoots').

2.5. Tomato plant growth and fruit production

Plant growth was monitored in season I between 17 DAP and 187 DAP, and in season II between 56 DAP and 225 DAP. With respect to each plant, the diameter of the two stems at the point of emergence of the first leaf was measured, and the numbers of expanded leaves and fruit clusters per branch were counted. Stem diameter was estimated from the mean of ten plants per replicate. The fruit production rate was monitored from 74 to 222 DAP in season I and from 118 to 236 DAP in season II, by recording the number and weight of red-ripe stage (USDA, 1991) fruits from ten plants per plot. The different sampling dates between the two seasons were related to the different plant growth and fruits ripening rate of the studied tomato cultivars. The total number of fruits per plant, the average fruit fresh weight and the yield (as kg $plant^{-1}$) were determined.