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Solarization working like a "solar hot panel" after compost addition sanitizes soil in thirty days and preserves soil fertility

L. Morra[a,*], R. Carrieri[a], F. Fornasier[b], P. Mormile[c], M. Rippa[c], S. Baiano[a], M. Cermola[a], G. Piccirillo[a], E. Lahoz[a]

[a] Consiglio per la Ricerca in Agricoltura e l'analisi dell'Economia agraria (CREA), Research Centre for Cereal and Industrial Crops, Laboratory of Caserta, Via Torrino, 2, 81100, Italy

[b] Consiglio per la Ricerca in Agricoltura e l'analisi dell'Economia agraria (CREA), Research Centre for Viticulture and Enology, Unit of Gorizia, Italy

[c] Institute of Applied Sciences and Intelligent Systems of CNR, Via Campi Flegrei 34, 80072 Pozzuoli (Naples), Italy

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ABSTRACT

An innovative soil solarization method working like a solar hot panel, was applied on a soil previously amended with compost, to test for sanitation efficiency in controlling soil-borne fungi and preserving soil chemical and biological fertility. Soil was sprayed on surface with biodegradable black liquid consisting in a polysaccharide gel-carbon black mixture then covered with a clear plastic film. Two concurrent experiments were carried out under tunnel. In the first one, thirty-days long solarization cycles were carried out with the aim to measure thermal efficacy and survival of three fungal pathogens by comparing the innovative to the conventional solarisation. The innovative solarization improved sanitation with respect to *Sclerotinia sclerotiorum*, *Fusarium oxysporum* f. sp. *melonis* and *Plectosphaerella cucumerina*, it increased soil maximum and minimum temperatures, as well as the sum of hours conventionally considered effective for fungi disinfection (> 37 °C). In the second experiment, carried out in 2014–2016, the innovative solarization was scheduled insight a crop sequence of leafy vegetables for the ready-to eat salads sector and the efficacy of organic amendment for soil fertility preservation was tested too. A yearly organic amendment by olive husk compost at rate of 15 t ha^{-1} was applied before innovative solarization. This approach was compared to i) soil disinfection by standard farm solarization plus mineral fertilization; ii) control consisting in soil not solarized nor fertilized. K_2SO_4-extractable C and N, microbial biomass and enzymatic activities associated with biogeochemical cycles of C, N, P, S, were monitored before and after solarization. Results showed that soil amendment associated to innovative solarization almost cancelled detrimental effects of solarization on biochemical activities, increased soil organic C content of 2 g kg^{-1} and increased the yield of leafy vegetables by 30% compared to both control not treated and standard solarization.

1. Introduction

The reduction of agrochemicals is one of the major current challenges in agriculture, including soil-borne pathogens control. Soil solarization alone or combined with organic amendment, is a non-chemical approach that represents one of the most important alternatives in terms of environmental sustainability for weeds, pests, and soil-borne pathogens management in agricultural soils (Katan, 2017; Carrieri et al., 2013). Solarization consists of covering the soil surface with a thin clear plastic tarp to enhance accumulation of heat during summer months. Starting from the first application (Katan et al., 1976) and still now, solarization has important technical limitations. Indeed, an improvement of the technique with respect to the impact on soil ecosystem, duration of soil covering and efficiency in heat accumulation in the soil is needed (Katan, 2017). In the last decade, plastic films with innovative thermal and optical properties have been proposed with the aim to improve the efficacy of soil solarization (Castello et al., 2017; Vitale et al. 2011). Nevertheless, solarization requires usually long times of application (40–60 days) in order to reach high temperature up to 30 cm depth in the soil for a time sufficient to sanitize it. The use of soil solarization has caused a concern about the side effects of solarization on soil microbial populations, soil functionality, nutrients availability and soil organic carbon mineralization. An increase of dissolved organic matter, soluble forms of nitrogen (NH_4^+, NO_3^-) and some macro and mesonutrients (K, Mg, Ca, Na) has been detected in soils after solarization (D'Addabbo et al., 2010). Soluble forms of

* Corresponding author.
E-mail address: luigi.morra@crea.gov.it (L. Morra).

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nitrogen accumulation are attributed to higher decomposition rates of organic matter and mineralization of dead microbial biomass including nitrifying bacteria, during soil solarization (Grünzweig et al., 1999). Agronomic investigations about solarization evidenced an increase in crop yield (Chen and Aviad, 1990; Chen et al., 2000) and significant changes in composition and richness of soil microbial communities (Magnifico et al., 1996; Gelsomino and Cacco, 2006; Bonanomi et al., 2008; Yokoe et al., 2015). A decrease of microbial biomass and a concurrent increase of soil respiration and specific respiration activity (qCO2) as an effect of the thermal stress was detected after a 40-day solarization under tunnel (Morra et al., 1998). Recent studies about greenhouse solarization report that organic matter addition exert a "protective effect" against heat detrimental effects (Okur et al., 2006; Tamietti and Valentino, 2006; Scopa and Dumontet, 2007).

In the Sele River Plain (Province of Salerno, Campania Region, Southern Italy), the increase of crop areas devoted to leafy vegetables crops (fresh cut or head harvested) as well as the traditional crops (tomato, muskmelon, lettuce, pepper, etc.) under tunnel-greenhouses reached an extension of 5400 ha in the last years. Effective, efficient and cost-effective alternative to soil chemical fumigants (i.e., Metam Sodium, Chloropicrine) is still an unsolved problem in order to reduce the environmental impacts of these crops. Three of the most important soil-borne fungal pathogens affecting crops in the area are: *Sclerotinia sclerotiorum*, *Fusarium oxysporum* f. sp. *melonis* and *Plectosphaerella cucumerina*. *Sclerotinia sclerotiorum* (Lib.) De Bary is the causal agent of white mold, one of the most important fungal diseases affecting several horticultural crops in field and in greenhouse, mainly in spring and autumn (Lahoz et al., 2009). *Fusarium oxysporum* Schlecht., a common constituent of fungal communities in the rhizosphere of plants (Burgess, 1981; Gordon and Martyn, 1997), is one of the most destructive phytopathogenic fungi across the world. Diseases induced by *formae speciales* of *F. oxysporum* are difficult to control (Minerdi et al., 2009; Yanlai et al., 2016). One of the most important pathogen is *F. oxysporum* f. sp. *melonis* Leach & Currence emend. Snyd. & Hans. that causes wilt disease on melon (*Cucumis melo*). *Plectosphaerella cucumerina* (L.) Laterr. is a polyphagous fungus, recently reported as a severe pathogen in various horticultural crops – such as parsley, melon and lamb's lettuce – in Southern Italy (Carlucci et al., 2012; Carrieri et al., 2014).

We tested disinfection effectiveness and efficiency of a new solarization method which is based on the reproduction of a thermal solar panel at agronomical level by two concurrent experiments carried out in 2014–2016. The first experiment aimed to assess: a) the thermal efficacy of the new solarization method, compared to the traditional one, and the consequent possibility to reduce to 30 days the time of treatment; b) the effect of the new solarization procedure on the survival of *S. sclerotiorum, F. oxysporum* f. sp. *melonis* and *P. cucumerina*. In a second experiment, we monitored changes in soil organic C, soil microbial biomass, enzyme activity and K_2SO_4-extractable C and N as influenced by solarization treatments and in presence or not of organic amendments by olive husk compost.

2. Materials and methods

2.1. Site of experiment

Both the experiments were carried out in an area of about 3500 m^2 covered by multichapel plastic tunnels (Sunsaver diffused film by Ginegar, Israel) with a cubature ratio of 4 $m^3\,m^{-2}$. The soil under tunnel had a sandy-clay texture (sand, silt and clay respectively 520–120–360 g kg^{-1}), pH 8.2, electrical conductivity 1.38 dS m^{-1}, soil organic carbon content 5.4 g kg^{-1}, total N 0.62 g kg^{-1}, C/N 8.7, Olsen P 19 mg P_2O_5 kg^{-1}, K_2O 210 mg kg^{-1}. The private farm hosting the trials is sited in Sele River valley (40°31′27.5″ N–14°57′51.3″ E), south of Salerno (Campania Region) and was devoted to the production of fresh-cut leafy vegetables, mainly rocket and basil.

2.2. New method of solarization

The soil solarization tested in our experiments simulates a thermal solar panel basically made up of a black base (heat collector) and a thermal glass as cover, in order to optimize the "greenhouse effect": the heat is trapped in the box without significant energy loss (Mormile et al., 2013, 2016). A biodegradable black liquid consisting in a gel-carbon black mixture was sprayed (1,5 L m^{-2}) on the soil previously tilled and wetted to field capacity. The black liquid was a mixture of water and a polysaccharide (3:1 ratio) plus the addition of carbon black (100 g 10 L^{-1}). The gel contained: locust bean (*Ceratonia siliqua* L.) gum (galactomannans), agar as gelling agent to favor the process of the gel physical curing, ethanol as inhibitor of agglomeration of locust bean gum and glycerol as plasticizing agent. Once dried, the gel has a hydration and expansion capacity up to 25% of its initial volume, it was covered by Polysolar, a clear, anti-drop, 0.03 mm thick, plastic film. The standard farm solarization procedure consisted in covering the soil, previously tilled and wetted to field capacity, with a clear plastic film (Polysolar, 0.03 mm thick).

2.3. Experiment 1

2.3.1. Soil temperature recording

In order to assess the thermal performance of the innovative solarization in a 30-days long period, three trials were carried out in three consecutive years: from July 4th to August 3rd, 2014; from July 21st to August 20th, 2015; from July 29th to August 28th, 2016. Three treatments were compared: standard farm solarization (SFS), innovative solarization simulating a solar thermal panel (InnS) and unsolarized control (CNT). Each treatment was applied in 25 m^2 plots in a tunnel of 32.5 × 7.5 m. Four thermocouples per plot were placed at 10, 20 and 30 cm depth in the soil and one was used for air temperature monitoring; all of them were connected to a data-logger with a record interval of 10 min. The sums of hours in which temperatures exceeded the threshold of 37 °C or 42 °C were calculated. In 2016, monitoring equipment failure prevented the detection of temperature in soil.

2.3.2. Viability tests of soil-borne pathogens

Viability of propagules of fungi *S. sclerotiorum* (Ss), *F. oxysporum* f. sp. *melonis* (Fom) and *P. cucumerina* (Pc) was determined after solarization in 2014 and 2016 using fungi strains from collection of the Council for Agricultural Research and Economics (CREA) of Caserta (Italy) and previously isolated from crops located in the Sele Plain. The protocol was adapted starting from that described by Vitale et al. (2013). Fungi were grown in laboratory 10 days at 24 °C in the dark – in 3L flasks containing sterilized barley grains, previously soaked overnight at 4 °C with a 10% glucose solution. After 10 days, 100 colonized grains were put in little nylon bags (0.45 μm mesh). For each fungus, three bags/replicates were placed at 10, 20, 30 cm soil depth, for a total of 27 bags per treatment. After 30 days, the bags were collected, washed with sterile distilled water, and air-dried. For each bag, 20 grains were placed in each of 5 Petri dishes (9-cm in diameter) containing potato dextrose agar (PDA; Conda, Spain). The plates were then incubated at 24 °C in the dark. After 5 days, the plates were monitored to verify if the corresponding fungi started to grow again from the grains. Colonies grown from recovered grains, not immediately associated to the expected fungal species, were sub-cultured on PDA in order to obtain a right identification. For each fungus at each depth, the viability was calculated as percent of grains from which the fungus was re-isolated.

2.4. Experiment 2

2.4.1. Experimental design and management of field trial

The agronomic trial lasted for twenty months, from June 2014 to February 2016. The experimental design was set in a part of covered