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Effect of repeated cycles of soil solarization and biosolarization on corky root, weeds and fruit yield in screen-house tomatoes under subtropical climate conditions in the Canary Islands

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ABSTRACT

Soil solarization is a non-chemical soil disinfestation method proven effective against soil-borne pathogens and weeds. However, it should be assessed under local cropping conditions before it can be implemented in commercial crops, since the process is highly dependent on climate conditions, among other factors. Soil biosolarization combines biofumigation with solarization to improve its effectiveness but knowledge about its use on tomato crops is still rather scarce and limited to nematode control. We have tested the effectiveness of soil solarization, biosolarization and fumigation with metam sodium over three tomato cropping seasons, to control corky root caused by *Pyrenochaeta lycopersici* and weeds under screen-house conditions in the Canary Islands (Spain). During the three seasons, maximum soil temperatures at 10 cm depth in solarized and biosolarized plots were about 10 °C higher than in controls, rising up to 41.4–43.3 °C in solarization and 43.0–44.7 °C in biosolarization, with an accumulated number of hours exceeding 40 °C of 48.8–138.2 and 92.3–204.7 h in solarized and biosolarized plots, respectively. The most effective treatment was biosolarization, which significantly increased tomato yield by 12.4% in 2001–02; 22.8% in 2002–03 and 22.2% in 2003–04, and reduced corky root severity in the last two seasons. Corky root was also significantly reduced by solarization in 2003–04, whereas there was no difference between metam sodium and control plots in any season. Weed infestation was evaluated in 2002–03 and 2003–04, in which weed density in biosolarized plots was significantly lower than in controls (88.8% and 50.6% reduction at 45 and 165 days after tomato transplanting in 2002–03; and 69.6% after 120 days in 2003–04). In contrast, weeds were not controlled by solarization, and inconsistent results were obtained with metam sodium. Here we show that soil biosolarization is clearly a way to improve the effectiveness of soil solarization under less favorable environmental conditions, like those prevailing in tomato screen-houses in the Canaries, and a feasible alternative to chemical fumigation for the control of corky root and weeds.

1. Introduction

Tomato is the second most important crop in the Canary Islands (Spain) after banana, with an annual production of 125,741 t dedicated mainly to export, concentrated in the winter months (Ministry of Agriculture and Fishing, Food and Environment of Spain, 2015). Due to the subtropical climate prevailing in the Canaries, tomato can be grown throughout the year in simple protective structures consisting of a screen-covered frame to prevent pests from entering. Therefore, winter tomato production is possible without the heating costs incurred in tomato greenhouses located in northern latitudes (Baptist et al., 2013). In addition, screen-houses have very low initial cost and maintenance, and are extensively used in the Canaries as a production system for tomato crops, as well as in other tropical and subtropical regions.

Corky root of tomato (*Pyrenochaeta lycopersici* Schneider and Gerlach) is a common disease in greenhouse and field-grown tomatoes. The fungus attacks the parenchyma tissues of the root

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system causing cortical lesions that become dark-brown, swollen and fissured. Severely affected plants show leaf yellowing and root failure, with yield loss estimates of up to 70% reported by Campbell et al. (1982). Corky root is often considered a cool temperature disease because the development of symptoms is stimulated by low temperatures (Shishkoff and Campbell, 1990). However, it is also spread in warm regions such as Southern Europe where significant problems in tomato greenhouses caused by *P. lycopersici* have been reported in Italy (Bubici et al., 2006; Cascone et al., 2000; Garibaldi and Tamietti, 1984; Vitale et al., 2011) and Greece (Tjamos, 1984). In the Canary Islands, corky root symptoms in tomato crops were first recognized in the late 1970s during cooler winter months, the involvement of *P. lycopersici* being demonstrated by isolating the pathogen (Rodríguez, 1983).

Management of corky root was largely based in the past on regular preplant soil fumigation with methyl bromide, which is now banned due to its depleting effect on atmospheric ozone. Other fumigants such as cloropicrin and metam sodium are also effective, particularly if the soil is tarped (Campbell et al., 1982). However, in the European Union (EU), metam sodium application is limited to one application every third year on the same field according to Regulation (EU) No 359/2012, and chloropicrin is currently not authorized pursuant to Regulation (EU) No 1381/2011. Despite this, chloropicrin remains in use within the EU due to the legal possibility of the member states allowing the use of active substances for a limited period when necessary, to control a serious danger to plant health which cannot be contained by other available means. Chloropicrin has been authorized in the Canary Islands and other Spanish regions for tomato crops according to the Spanish Regulation of 12th April 2016 (Ministry of Agriculture and Fishing, Food and Environment of Spain), but this temporary authorization is no longer in force at present. Hence, finding alternatives to chemical fumigants remains a challenge for pest management in tomato crops.

Chemicals other than fumigants have been sparsely tested for the control of corky root. Bubici et al. (2006) have reported the effectiveness of azoxystrobin and trifloxystrobin, two strobilurin fungicides, and also the plant defense activator acibenzolar-S-methyl. However, the latter can cause severe phytotoxic symptoms depending on dosage and application procedure. In addition, chitin amendments to soils infected with corky root resulted in a significant increase in root yield, which has been related to the known plant inducer resistance effect of this compound (Giotis et al., 2009). On the other hand, the effectiveness of compost amendments to control corky root is greatly dependent on compost properties, and can range from reducing disease to increasing it. According to Hasna et al. (2009), compost with a low concentration of NH_4-N and a high concentration of Ca reduced corky root symptoms in pot experiments, but further investigation should be conducted in commercial growing conditions. Similarly, although the potential of commercially available biocontrol agents against *P. lycopersici* have been pointed out (Minuto et al., 2006), their application to commercial crops is not currently considered a feasible alternative (Hasna et al., 2009). Besides this, cultivars resistant to *P. lycopersici* are not currently available although resistant rootstocks (e.g. Beaufort) are on hand (Louws et al., 2010). Grafting plants on resistant rootstocks provides good disease control but the plant cost is significantly increased.

Soil solarization is a soil disinfestation method based on the use of solar radiation to eradicate or reduce the inoculum existing in the soil. The method was developed in Israel in the 1970s and involves the use of transparent plastic sheets to cover the soil in order to increase its temperature to levels lethal to pathogens (Katan, 1981, 2015; Katan et al., 1976). Most research conducted with solarization on tomato crop has been focusing on nematodes and fungal pathogens, and several studies have investigated the effect of soil solarization, alone or in combination with chemical fumigation, to control *P. lycopersici* (Antoniou et al., 2014; Cascone et al., 2000; Garibaldi and Tamietti, 1984; Lombardo et al., 2012; Tjamos, 1984; Vitale et al., 2011). In addition, solarization can provide an effective weed control (Katan, 1981), but little information is available in this respect in tomato crops (Candido et al., 2008; Chellemi and Mirusso, 2006). Weeds are usually managed in this crop through preparatory tillage and a pre-planting herbicide, and later, through interrow tillage or post-emergence herbicide. Besides this, black plastic mulch can help to reduce the chemical need. Currently, herbicides such as diquant, glyphosate, metribuzin, napropamide, pyridate, pendimethalin, rimsulfuron and several others, are authorized in Spain for weed control in tomato crops (Ministry of Agriculture and Fishing, Food and Environment of Spain, 2016).

Biofumigation, consisting in the use of biocidal gases resulting from the degradation of soil organic amendments, is also reported to control soil pathogens. However, information about the effectiveness of organic matter inputs for controlling corky root is very scarce (Giotis et al., 2009). Biofumigation in combination with solarization, referred to as biosolarization, can often improve the efficiency of these methods used separately (Stapleton, 2000). In this regard, repeated biosolarization is being successfully applied in mainland Spain to control fungal pathogens in strawberry and pepper crops (Domínguez et al., 2014; Guerrero-Díaz et al., 2014; Martínez et al., 2011). However, studies addressed to researching the effect of biosolarization on tomato crops are limited to nematodes (Klein et al., 2012; Oka et al., 2007) and yield increment as a result of the improvement of the chemical properties of the soil (Mauromicale et al., 2010).

The overall mode of action of soil solarization and biosolarization is complex. Besides the direct thermal inactivation of crop pests, these treatments increase the release of mineral nutrients into the soil solution and of biocidal volatiles into the soil atmosphere, and cause important changes in soil microbiota, all of which contribute to a healthier root environment and higher plant productivity (Katan, 1981; Stapleton, 2000). Accordingly, the effectiveness of the process is affected by many factors, including climatic and weather conditions, properties of the plastic film and duration of coverage, soil properties and moisture, in addition to the type and amount of organic amendment applied in biosolarization (Cascone et al., 2000; Chellemi and Mirusso, 2006; Domínguez et al., 2014; Garibaldi and Tamietti, 1984; Klein et al., 2012; Mauromicale et al., 2010; Oka et al., 2007; Ozores-Hampton et al., 2012; Vitale et al., 2011). Moreover, data on the long-term effects of solarization, and on repeated solarization cycles is still scarce (Candido et al., 2008). Due to this complexity, the effectiveness of the technique should be assessed under local cropping conditions before implementation in a given region. In this respect, information on the effectiveness of soil solarization and biosolarization in the Canary Islands is lacking. Therefore, our objectives were to evaluate (i) the effect of repeated soil solarization on corky root severity, weed infestation and tomato yield, under commercial growing conditions in the Canaries; and (ii) if combining organic amendments with soil solarization improves its effectiveness.

2. Materials and methods

2.1. Field location

Experimental plots were established in a 500 m^2 screen-house (white screen, 35 mesh) located in Güimar (Southeastern Tenerife, Canary Islands, Spain; 28°19′N, 16°23′W, altitude 156 m),