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Impact of elevated CO_2 concentrations in the soil on soil solarization efficiency

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ABSTRACT

Solarization is a method of heating moist soil by covering it with transparent polyethylene sheets to trap solar radiation. It involves the use of heat as a lethal agent for soil-borne pathogens. Soil temperature under polyethylene sheet cover is a function of incoming radiation and thermal characteristics of the polyethylene sheets and the soil. In order to study the effect of soil CO_2 concentrations on soil solarization efficiency, clay soil samples infested with *Verticillium dahliae* were exposed to different CO_2 concentrations [350, 700, 1050, 1400, 1750 μL CO_2 L air^{-1}] and incubated in hot water baths at 35, 40, 45, 50 and 55 °C. Moreover, field plots were exposed to the same CO_2 levels during soil solarization in three periods [1st of July to 30th of September, 1st of August to 30th of September, and 1st to 30th of September]. Recorded temperatures of 35–55 °C during the three soil solarization periods were lethal to *V. dahliae*. At 35 and 55 °C, the exposure time for LD_{90} was 24 days and 6 h respectively for *V. dahliae* with ambient soil CO_2 content. High CO_2 content in the soil resulted in increasing maximum soil temperatures and soil heat flux while reducing the time required for LD_{90}. The required time for LD_{90} of *V. dahliae* in soil heated at 35 °C, reduced from 24 days with ambient CO_2 content to 15 days at 1750 μL CO_2 L air^{-1}. Sub-lethal soil temperatures were raised to lethal levels with increasing CO_2 content in the soil. A linear "negative" relationship existed between logarithms of times required to kill 90% of *V. dahliae* microsclerotia and temperatures for all soil CO_2 enrichment levels. The fungus was killed in field soil solarized for the necessary time periods. It was found that the addition of CO_2 shortens the required time to kill the fungus *V. dahliae* during solarization and increased the activity of the sub-lethal soil temperatures. Levels of CO_2 and temperature necessary to kill the fungus are useful for evaluating the progress of soil solarization under field conditions.

1. Introduction

Solarization (also referred to as solar heating) is a method of heating the soil by using polyethylene sheets as mulching over moistened soil, to retain solar radiation during the hot season (Katan et al., 1976; Horowitz et al., 1983; AL-Karaghouli and AL-Kayssi, 2001). Soil-borne pathogens may be killed by lethal heat (>40 °C) and weakened by sub-lethal heat (<38–40 °C) to the extent that they are unable to cause damage to plants or they are more susceptible to chemical toxicants (Stapleton, 1997; Banu et al., 1998; Chauhan et al., 1998). Extensive studies by many workers worldwide have shown that soil temperatures below 45 °C, which are often considered to be "sub-lethal", tend to extend the period needed for controlling soil-borne pathogens (Bigelow, 1921; Smith, 1923; Grooshevoy et al., 1941; Munnecke et al., 1976; Van Uden and Vidal-Leiria, 1976). Much has been written about solar solarization, which has been successfully used to control soil-borne pathogens and weeds (Katan et al., 1976; Mahrer, 1979; Grinstein et al., 1979; Katan, 1981; Mahrer et al., 1984; Avissar et al., 1986; AL-Karaghouli et al., 1990; AL-Kayssi and AL-Karaghouli, 1991). But, little is known about the influence of CO_2 on soil solarization efficiency especially at sub-lethal soil temperatures. During the past decade a number of studies have been conducted to assess the influence of elevated atmospheric CO_2 on aboveground plant community diversity and physiology as well as belowground root dynamics and root exudates (Van Veen et al., 1991; Curtis et al., 1994; Day et al., 2000; Griffiths et al., 2000; Schortemeyer et al., 2000; Wiemken et al., 2001), and nutrient availability (Hungate et al., 1999; Johnson et al., 2001). In most cases, these investigations document the impact of elevated CO_2 upon plant growth and water requirements, but the reaction of the belowground microbial community has been less clear-cut. Some studies have reported no effect of elevated CO_2 on soil biota (O'Neill et al., 1987; Zak et al., 1997), while others have reported increases in microbial activity (Rouhire et al., 1994), in microbial biomass (Diaz et al., 1993; Rice et al., 1994), or in the number of mycorrhizal infections (O'Neill et al., 1987).

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The objective of the present study was to evaluate the effect of CO_2, temperatures and exposure time on survival of the soil-borne pathogen *V. dahliae* in both laboratory and field studies.

2. Materials and methods

2.1. Laboratory experiment

Soil infested with *V. dahliae* was collected from the upper 0.20 m of the soil profile in Baghdad (AL-Mada'in). The soil was alluvial clay, with a population density of *V. dahliae* of 168 microsclerotia g^{-1} of soil and had a water content at field capacity of 31.4%. Soil samples were passed through a 6-mm-mesh screen and stored at 4 °C. The site had been cultivated with vegetable crops (tomatoes, eggplants, cucumbers and peppers) frequently during the last decade under plastic-house conditions. Thirty grams of soil was placed in test tubes 12 mm in diameter and 210 mm in height. A predetermined amount of water was added to each tube to adjust soil water content to field capacity. Test tubes were capped with plastic tops, which retarded water loss and gas exchange. Six CO_2 concentrations were used in this experiment. They were ambient soil CO_2 78 μL CO_2 L air^{-1} (C1), and CO_2 concentrations 350, 700, 1050, 1400 and 1750 μL CO_2 L air^{-1} (C2, C3, C4, C5 and C6 respectively). CO_2 was injected into the soil to a depth of 0.1 m below the soil surface in each test tube by a single hole micro-syringe. Soil air from each test tube was sampled by micro-syringe to determine the injected CO_2 concentration after equilibration. The CO_2 concentration of sampled soil air was quantified using a gas chromatograph (GC 14-A, Shimazdu, Kyoto, Japan) with a thermal conductivity detector. Tubes were allowed to equilibrate overnight and the next day were immersed in hot water baths maintained at 35, 40, 45, 50 and 55 ± 0.2 °C (T1, T2, T3, T4 and T5, respectively) placed in an incubator at 28 ± 0.5 °C. Three tubes per CO_2 concentration were treated for each temperature and exposure time. Then, the soil was removed from the test tubes of each treatment, bulked, and assayed for *V. dahliae* microsclerotia estimation.

2.2. Field experiment

The field experiment was carried out at AL-Mada'in Research Station of the Solar Energy Research Centre. The station is located 30 km south of Baghdad, Iraq, at 33 °14′N, latitude and 44 °14′E, longitude at 34 m above sea level. The climate is semi-arid and sub-tropical with an average rainfall of 250 mm. The soil is a typical (Torrifluvents) clay soil, composed of 18% sand, 39% silt and 43% clay, with an average *V. dahlia* population density of 168 microsclerotia g^{-1} of soil. Individual plots 3 m × 3 m were arranged in a randomized complete block design consisting of six CO_2 treatments each with four replications. Pure CO_2 (gas cylinder source) was injected into the soil at 0.018, 0.035, 0.046, 0.070 and 0.088 L m^{-2} to produce concentrations of 350, 700, 1050, 1400 and 1750 μL CO_2 L air^{-1} (C2, C3, C4, C5 and C6, respectively) on three occasions: July 1st, August 1st and September 1st (P1, P2 and P3, respectively). The ambient soil CO_2 content (C1) was 78 μL CO_2 L air^{-1}. Bottled Carbon Dioxide (CO_2) Emitter System model (BCDE-1) was used for CO_2 injection into the soil to a depth of 0.10 m below the soil surface at a flow rate of 3 L min^{-1}. The number of injection points was 9 per m^2. A full description of the injection system was provided by Okada et al. (2001). Concentrations of injected CO_2 were determined by the method of Osozawa and Kubota (1987). The diffused gas (2 cm^3 samples) was sampled at 15 min-intervals by a single hole micro-syringe according to Rolston (1986). Gas concentrations were analyzed by a gas chromatograph (GC14-A, Shimazdu, Kyoto, Japan) with a thermal conductivity detector. Before mulching, the soil was wetted to field capacity to 1 m depth and injected with CO_2. No additional irrigations were made after mulching the soil surface with transparent polyethylene sheets (180 μm thick). Special care was taken to keep the soil in good tilth before mulching, allowing close contact between the polyethylene sheets and the soil surface and preventing the formation of "air pockets" which reduce heat conduction. The edges of the polyethylene sheet were accurately buried at the border of each plot. Mulching was carried out as described by Katan et al. (1976). Soil temperatures at depths of 0.01, 0.05, 0.10, and 0.20 m (D1, D2, D3 and D4, respectively) and air temperature at 0.10 m above ground level were monitored by means of shielded copper-constantan thermocouples. Measurements of net total solar radiation (0.4–60 μm) were made with miniature net radiometers mounted horizontally with the sensing surfaces 0.10 m above the ground surface. The analog signals from the sensors were converted into digital signals for the Hewlett-Packard Automatic Data Acquisition/Control System Model 3054A. The output data were printed hourly using a Hewlett-Packard Model 9845B computer connected on-line with the data acquisition system. Soil solarization efficiency "using a bioassay" was tested in the three periods P1 (July 1st to September 30th), P2 (August 1st to September 30th) and P3 (September 1st to 30th). Thus, the soil solarization duration periods were 90, 60 and 30 days for the three periods respectively.

Table 1
Mean monthly maximum soil temperatures (°C) at different CO_2 concentrations C1 (78 μL CO_2 L air^{-1}), C2 (350 μL CO_2 L air^{-1}), C3 (700 μL CO_2 L air^{-1}), C4 (1050 μL CO_2 L air^{-1}), C5 (1400 μL CO_2 L air^{-1}) and C6 (1750 μL CO_2 L air^{-1}) in the soil during three solarization periods P1 (July 1st to September 30th), P2 (August 1st to September 30th) and P3 (September 1st to 30th) and at four soil depths D1 (0.01 m), D2 (0.05 m), D3 (0.10 m) and D4 (0.20 m).

CO_2 concentration	Solar solarization periods		
	P1	P2	P3
Soil depth D1			
C1	53.17	50.17	46.17
C2	54.07	51.08	47.11
C3	54.70	51.71	47.75
C4	56.72	53.72	49.77
C5	59.01	56.03	52.13
C6	65.77	62.78	58.73
LSD ($P < 0.05$, $df = 5$)	0.87	0.83	0.82
Net solar radiation (W m^{-2})	710.66	680.73	570.86
Air temperature (°C)	50.23	47.06	43.41
Soil depth D2			
C1	49.00	46.00	42.00
C2	50.18	47.20	43.21
C3	50.45	47.55	43.54
C4	51.84	48.91	44.93
C5	52.63	49.61	45.66
C6	59.61	56.51	52.59
LSD ($P < 0.05$, $df = 5$)	0.89	0.81	0.84
Soil depth D3			
C1	45.01	42.06	38.13
C2	45.90	42.92	38.94
C3	47.47	44.46	40.51
C4	48.26	45.29	41.30
C5	50.23	47.26	43.29
C6	51.28	48.31	44.33
LSD ($P < 0.05$, $df = 5$)	0.81	0.83	0.78
Soil depth D4			
C1	43.11	41.14	36.16
C2	44.00	41.00	37.01
C3	44.31	41.36	37.41
C4	45.05	42.11	38.14
C5	45.58	42.61	38.63
C6	46.37	43.41	39.45
LSD ($P < 0.05$, $df = 5$)	0.78	0.73	0.75