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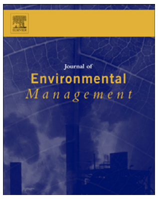

Research article

Impact of elevated carbon dioxide on soil heat storage and heat flux under unheated low-tunnels conditions

A.W. Al-Kayssi*, S.H. Mustafa

Soil and Water Resources Department, College of Agriculture, Tiktit University, Tikrit, P.O. Box 42, Iraq

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ABSTRACT

Suboptimal regimes of air and soil temperature usually occur under unheated low-tunnels during winter crop cycles. CO_2 is one of the most important gases linked to climate change and posing challenge to the current agricultural productivity. Field experiment was conducted in unheated low-tunnels (10.0 m long, 1.5 m wide and 1.0 m high) during winter and spring periods to evaluate the increasing CO_2 concentration (352, 709, 1063, 1407, and 1761 ppm) on net radiation budget, soil-air thermal regime and pepper plants growth development and yield. CO_2 was injected into each hollow space of the tunnel double-layer transparent polyethylene covers. Recorded integral net longwave radiation increased from 524.81 to 1111.84 Wm^{-2} on January when CO_2 concentration increased from 352 to 1761 ppm. A similar trend was recorded on February. Moreover, minimum soil surface and air temperatures were markedly increased from −1.3 and −6.8 °C to 3.4 and 0.6 °C, when CO_2 concentration increased from 352 to 1761 ppm. Additionally, soil heat flux as well as soil heat storage increased with increasing CO_2 concentrations accordingly. Increasing the tunnel minimum air and soil temperatures with the CO_2 concentration treatments 1063, 1407 and 1761 ppm reflected in a significant pepper yield (3.19, 5.06 and 6.13 kg m^{-2}) due to the modification of the surrounding plants microenvironment and prevented pepper plants from freezing and the accelerated the plant growth. On the contrary, the drop of minimum air and soil temperatures to freezing levels with the CO_2 concentration treatments 352 and 709 ppm resulted in the deterioration of pepper plants development during the early growth stages on January.

1. Introduction

Greenhouse cultivation can provide high-quality products all-year round with an efficient use of resources, such as water, fertilizers, pesticides and land-labour (Alberto et al., 2004). Consequently, in the last decades plastic greenhouses have developed rapidly and widespread in mild-winter climates (Castilla, 2002), such as the Mediterranean Basin countries, where the mild temperature during winter makes it possible to produce vegetable crops in very simple shelters (Castilla and Hernandez, 2005).

The cool, short growing season characteristic of most arid and semi-arid regions limits commercial production of many vegetable crops. Production of warm-season vegetable crops such as pepper, cucumber and tomatoes is particularly difficult unless means are employed to improve the growing conditions (Doug, 2003). Plastic tunnels are becoming an increasingly important production tool for vegetable growers in arid and semi-arid regions. They provide a protected environment relative to the open field, allowing for earlier or later production of many vegetable crops, and they typically improve yield and quality as well as diseases and pest management (Edward et al., 2009). At present, low tunnels (typically less than 0.75 m tall) represent the standard method for using plastics to enhance the growth of most vegetable crops (Wells and Loy, 1993). Low plastic tunnels are low-cost structures covered with plastic film, without climate control systems and with soil-grown crops (Perez-Parra et al., 2004). Typically, a single row of the vegetable crop is protected by each cover. By increasing air temperature, reducing wind damage and by providing a degree of frost protection, the low plastic tunnels accelerate crop development and extend the growing season (Wells and Loy, 1985; Waterer, 1992). Plastic tunnel microclimate is usually suboptimal for production of vegetable crops with edible fruits (Montero et al., 1985; Bartzanas et al., 2005), with a negative effect on yield and fruit quality (Lopez et al., 2008). Suboptimal air temperatures (nighttime values ranging between 5 and 10 °C) are often associated with low

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* Corresponding author.
E-mail address: wa.alkayssi@yahoo.com (A.W. Al-Kayssi).

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soil temperatures. Despite these unfavorable conditions, crop cycles starting in late autumn (cucumber) or early winter (pepper and tomatoes) have introduced in order to supply the market demand and benefit from higher prices.

Heating systems are not commonly used in these plastic tunnels because they are not considered economically viable (Lopez, 2003; Bartzanas et al., 2005). Many alternatives have been used to modify the soil-plant microenvironment under plastic-tunnel conditions. Among these alternatives, is the use of passive solar heating method and measures to enhance the greenhouse energy efficiency (Baille et al., 2006). They suggest that simple passive solar systems increasing solar heat storage in the soil during the day and releasing the energy during the night could significantly enhance the overall plastic tunnel efficiency, especially in areas that receive a significant input of solar radiation in winter. Among the passive systems, mulching could be of interest for improving the air/soil thermal regime during the early stages of crop cycles starting in winter such as tomato and pepper when the leaf area index is small and most of soil surface is free of vegetation (Bonachela et al., 2012). Plastic mulches have been used commercially on vegetables since the early 1960s. Much of the research was conducted on the impact of color (black and clear) on soil and air temperature, moisture retention, and vegetable yield (Emmert, 1957; Schales and Sheldrake, 1963, Tanner, 1974; Liakatas et al., 1986; Ham et al., 1993; Lamont, 1993; Stapleton, 2000; Lorenzo et al., 2005). Generally, temperatures under the plastic mulches are 0.55–1.11 °C warmer than outside air (Wells and Loy, 1993).

Another alternative is the use of thermal tubes. Thermal tubes are clear polyethylene tubes, 10–12 inches in diameter, filled with water which absorbs the solar energy during the day and slowly releases the energy as heat throughout the night. The tubes are laid alongside the plants and have been shown to raise the soil and plants canopy temperatures during cold periods (Secker et al., 1995).

One of the pre-eminent manifestations of climate change is the increase in atmospheric CO_2 concentration, from approximately 280 to 379 ppm. During the last twelve years the rate of increase of CO_2 is 1.9 ppm yr^{-1} and is forecasted to be as high as 570 ppm by the middle of this century with a consequence of 2.0–4.5 °C wormer earth surface (IPCC, 2007). Rise in CO_2 concentration in the atmosphere is changing the air temperature and precipitation patterns, posing challenge to the current agricultural productivity (Kimball et al., 2002; Jaggard et al., 2010). Much has been written about the impact of CO_2 enrichment on the modifications in canopy radiation utilization, growth and yield of many crops (Vanaja et al., 2008; Manderscheid et al., 2003, 2009; Isidro et al., 2009; Li et al., 2010; Saha et al., 2012, Saha et al., 2013, Aranjuelo et al., 2013; Saha et al., 2015a,b). But, little is known about the influence of CO_2 enrichment on microenvironment of the plastic tunnels. Vegetable cultivation under plastic tunnels provides valuable economic profits to farmers and is a steadily growing agricultural sector that in the last years has reached more than 2 million hectares worldwide (Scarascia-Mugnozza et al., 2011). Thus, it is important to understand the plastic tunnels microenvironment changes due to elevated CO_2 concentrations.

Therefore, the present investigation was conducted under low plastic tunnels to quantify the impact of elevated CO_2 (injected into the gap of the tunnels double layer covers) on net shortwave radiation, net longwave radiation, air/soil temperature, soil heat flux, soil heat storage and growth development of pepper plants.

2. Materials and methods

2.1. Site and climate

This study was conducted at the experimental farm of the University of Tikrit, Iraq located at 34° 36′N latitude and 43° 41′E longitude at an altitude of 250 m above mean sea level. The land of the experimental area had level topography.

The climate of the experimental site is semi-arid and subtropical with an average annual rainfall of 150 mm. The rainfall occurs from October to April (rainy season), which has uneven distribution. Averages of annual temperature, relative humidity, wind speed, sunshine duration per day and potential evapotranspiration are 17.4 °C, 52.9%, 2.8 m s^{-1}, 11.2 h, and 1986 mm, respectively.

The soil of the experimental site is a Typic Calcigypsids with a loam texture (composed 41% sand, 43.5% silt and 15.5% clay). The soil is shallow (0–0.13 m deep), very poor in organic matter (0.67%) and low plant nutrient. The available water holding capacity of the soil is low (0.158 and 0.099 m^3 m^{-3} for surface and subsurface horizons, respectively) with a moderate to high infiltration rate (3.72 and 10.98 cm h^{-1} for surface and subsurface horizons, respectively). Some physical characteristics of the soil at the experimental site are presented in Table 1.

2.2. Experimental details and crop management practices

The study was carried out with five semi-cylindrical low-tunnel-type greenhouses. Each tunnel was 10 m long, 1.5 m wide, and 1 m high, with its longer axis aligned in the North-South direction. The low-tunnels were constructed from a single frame structure of 13 mm (outer diameter) galvanized steel pipes. A 3 m wide buffer zone was maintained between each two-neighbor tunnels, to avoid the shading effects. The tunnels were covered with a double layer of 180 μm thickness transparent polyethylene (PE) sheets. The two PE sheets were welded from all sides forming a hollow space (≈0.10 m width) between the two sheets of the tunnel plastic cover, and a plastic air valve (model HI-498, HOLEE, Taiwan) was fixed on the outer PE sheet used to inject CO_2 into the hollow space. The plastic sheet had a transmissivity of 89% to shortwave radiation and 25% to longwave radiation (manufacturer's data). Doors were located on both ends of each tunnel for easy access. The tunnel both side vents were covered with insect proof screens (28 × 13 threads per cm, thread diameter 0.19 mm, porosity 32%) and they were managed manually.

Pure CO_2 gas (99.7% v/v CO_2 and less than 10 ppm CO) was released from a commercial grade cylinder fitted with a regulator

Table 1
Some physical properties of soil at the experimental site.

Soil depth cm	Bulk density Mg m^{-3}	Porosity %	Particle-size fractions			Soil texture	FC* m^3	PWP** m^{-3}
			Sand	Silt	Clay			
			g kg^{-1}					
0–13	1.42	46.28	410	435	155	Loam	0.231	0.073
13–72	1.37	48.20	–†	–†	–†	–†	0.124	0.025

*, ** Field capacity at 33 kPa, and permanent wilting point at 1500 kPa soil water tension, respectively.

†Unable to estimate the particles size distribution because of the rapid.flocculation of the aqueous soil suspension with high soil gypsum content.