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Effect of variable CO_2 enrichment on greenhouse production in mild winter climates

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Abstract

Variable CO_2 enrichment was evaluated under the autumn–winter climatic conditions prevailing in a coastal zone of southern Spain. Two adjacent identical greenhouses were used: control (without CO_2 enrichment) and enriched. Pure CO_2 was supplied to a greenhouse cucumber crop, maintaining in the greenhouse the air CO_2 concentration at close to 700 μmol mol^{-1} when the greenhouse was closed and 350 μmol mol^{-1} when the vents were open. CO_2 dynamics, efficiency of radiation and CO_2 use, and crop responses were determined over the growing season and compared to those of a similar cucumber crop grown in a non-enriched greenhouse. While the average diurnal concentration remained above 400 μmol mol^{-1} in the enriched greenhouse, significant CO_2 depletion was observed in the unenriched compartment, where the CO_2 concentration fell below 300 μmol mol^{-1} during 60% of the daytime when the crop was fully developed (leaf area index (LAI) ≈ 3). In the unenriched greenhouse, the average diurnal CO_2 depletion as well as the average mean concentration were highly correlated to the radiation intercepted by the crop, i.e. to the potential for biomass production. The average efficiency of CO_2 enrichment, i.e. the ratio of the amount of CO_2 sequestrated in the crop to the amount of artificial CO_2 delivered, was about 2% with respect to vegetative biomass, and about 6% with respect to fruit biomass. CO_2 enrichment affected mainly fruit biomass and had only a slight effect on leaf area index and vegetative biomass. The average increase in fruit production for both dry and fresh matter due to CO_2 enrichment was 19%, which agrees well with previous results on the agricultural response of cucumber to moderate CO_2 enrichment.

Keywords: CO_2 enrichment; Greenhouse; Water-use efficiency; Cucumber

1. Introduction

The lack of climate control in many greenhouse of Mediterranean countries results in an inadequate microclimate that negatively affects yield components and input-use efficiency. A better control of the greenhouse aerial environment can improve marketable yield and quality, and extend the growing season (Baille, 1999). Air CO_2 concentration is a relevant climate variable to be controlled in greenhouses as it has a marked effect on plant CO_2 assimilation. The atmospheric level limits the potential photosynthesis of most plant species and their productivity (Bowes, 1993). Inside an unenriched

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greenhouse, the CO_2 concentration drops below the atmospheric level whenever the CO_2 consumption rate by photosynthesis is greater than the supply rate through the greenhouse vents. CO_2 depletion depresses the daily photosynthetic rate, which is estimated to be about 15%, integrated over 29 days of simulation, when the concentration drops below 340 μmol mol^{-1} (Schapendonk and Gaastra, 1984). The poor efficiency of ventilation systems of the low-cost greenhouses in Mediterranean countries, coupled with the use of insect-proof nets (Muñoz et al., 1999) explains the relatively high CO_2 depletion (about 20% or more) reported in southern Spain (Lorenzo et al., 1990). The solution is to increase the ventilation rate through forced air, to improve design and management of the ventilation system, or to provide CO_2 enrichment. The latter is common in the greenhouse industry of Northern Europe as a means to enhance crop photosynthesis under the low radiation conditions that prevail during winter in those regions. Enrichment reportedly increases crop yield and quality under a CO_2 concentration of 700–900 μmol mol^{-1} (Kimball, 1986; Mortensen, 1987; Nederhoff, 1994). This situation explains why most of the present information on the effects of CO_2 enrichment on horticultural crops was gathered under climatic conditions and production systems (computerized climate-controlled greenhouses) typical of Northern Europe. Such knowledge and technology are not directly transferable to the environmental and socio-economic conditions of the Mediterranean countries, where CO_2 enrichment is not a common practice for several reasons. One of the main restrictions is the short time duration available for an efficient use of CO_2 enrichment, due to the need to ventilate for temperature control (Enoch, 1984). The fact that greenhouses have to be ventilated during a large proportion of the daytime makes it uneconomical to maintain a high CO_2 concentration during the daytime. However, some authors advise supplying CO_2 even when ventilation is operating (Nederhoff, 1994) to maintain the same CO_2 concentration in the greenhouse as outside and enriching to levels of about 700–800 μmol mol^{-1} during the periods when the greenhouse is kept closed, usually in the early morning and the late afternoon.

The aim of this study was to compile more information concerning the performance, over the growing season, of a dynamic strategy that combines CO_2 enrichment to 700 μmol mol^{-1} when the vents were closed with enrichment to the equivalent of the ambient concentration (350 μmol mol^{-1}) when the vents were open, and to do so under the typical conditions of Mediterranean countries. The interest was focused on the mean and long-term evaluation of this strategy based on crop response. The main goals of this paper are to (i) compare the trend of CO_2 consumption by the crop (estimated from dry-matter production) with the amount of CO_2 injected into the greenhouse, and (ii) determine the trend of CO_2 efficiency when applying the proposed strategy of CO_2 enrichment. Cucumber was chosen as the test crop because, besides its economical importance in greenhouse horticulture, it is known to present a significant and positive response to CO_2 enrichment (Nederhoff, 1994; Akilli et al., 2000).

2. Materials and methods

2.1. Greenhouse and climate control

The experiment was conducted in two adjacent identical multispan plastic greenhouses of 720 m^2 located at the CIFA experimental station, near Almería, Spain (36°30′N, 2°18′W). The greenhouses were equipped with a pipe heating system, roof and side vents, and a system for the injection of pure CO_2. All ventilators were permanently covered with insect-proof nets (25% of porosity). The greenhouse ventilation rates with full open vents were estimated, using a theoretical model described by Muñoz et al. (1999), to be between 5 and 16 $m^3\ s^{-1}$ under low to moderate wind speed (≈1 m s^{-1}), for leeward and windward directions, respectively. Ventilation started at 25 °C. To prevent high humidity, roof vents opened to 25% of full opening when relative humidity exceeded 85%. The pre-fixed heating set points (day/night) were: 22 °C/20 °C during the germination period, 18 °C/16 °C to the first fruit set and 16 °C/14 °C during fruit harvest. From 5 days after sowing onwards, pure CO_2 was supplied in one greenhouse, distributed through a network with one outlet below each plant. CO_2 enrichment was applied during the daytime according to two set points: 700 μmol mol^{-1} when the roof and side vents were closed and 350 μmol mol^{-1} when the roof vent opening was greater than 20% of full opening. The CO_2 concentration was continuously monitored and controlled through an infrared gas analyser (Siemens Corp., Mainz, Germany). The CO_2 injected into the enriched greenhouse was quantified indirectly by using the time (days) for CO_2 container depletion (27 and 35 kg) and referred to the greenhouse area. The other greenhouse was not CO_2 enriched but rather was maintained at the same temperature and humidity set points as the enriched one, and served as the control. The climatic variables (temperature, humidity and CO_2 concentration) were controlled by means of a commercial