

EFFECT OF IRRIGATION CYCLE ON CO₂ CONCENTRATION IN HYDROPONIC PLANTS UNDER CONTINUOUS ARTIFICIAL LIGHT

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ABSTRACT: The control of carbon dioxide (CO₂) concentration in hydroponic systems subjected to continuous artificial lighting is directly linked to environmental factors, particularly water management. This study aimed to evaluate CO₂ dynamics and their relationship with average temperature over a 24-hour cycle in a hydroponic lettuce (*Lactuca sativa* L.) crop in a closed environment, using constantly active white and red-blue LED lighting. CO₂ sensors coupled to an ESP32 microcontroller were used, which allowed for automatic data collection and transmission, recorded at hourly averages. Irrigation management was determined with a cycle of 12 hours and 45 minutes throughout the day, supplemented by three nighttime irrigations. The results showed that during the period of highest irrigation frequency (from 6 a.m. to 6 p.m.), CO₂ levels remained lower, indicating intense photosynthetic activity. On the other hand, during the nighttime period with lower irrigation frequency (from 6 p.m. to 6 a.m.), there was an increase in CO₂ concentration, possibly due to stomatal closure caused by water limitation. Graphical analysis revealed that temperature had a secondary influence on CO₂ dynamics, indicating that water management was the main regulating factor in this system.

KEYWORDS: Lettuce. Hydric. Management.

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EFEITO DO CICLO DE IRRIGAÇÃO NA CONCENTRAÇÃO DE CO₂ EM PLANTAS HIDROPÔNICAS SOB LUZ ARTIFICIAL CONTÍNUA

RESUMO: O controle da concentração de dióxido de carbono (CO₂) em sistemas hidropônicos submetidos à iluminação artificial contínua está diretamente ligado a fatores ambientais, particularmente ao manejo hídrico. Este estudo teve como objetivo avaliar a dinâmica do CO₂ e sua relação com a temperatura média ao longo de um ciclo de 24 horas em um cultivo hidropônico de alface (*Lactuca sativa* L.) em ambiente fechado, utilizando iluminação LED branca e vermelho-azul constantemente ativa. Foram utilizados sensores de CO₂ acoplados a um microcontrolador ESP32, que permitiram a coleta e transmissão automática de dados, registrados em médias horárias. O manejo da irrigação foi determinado com ciclo de 12 horas e 45 minutos ao longo do dia, complementados por três irrigações noturnas. Os resultados mostraram que durante o período de maior frequência de irrigação (das 6h às 18h), os níveis de CO₂ permaneceram menores, indicando intensa atividade fotossintética. Por outro lado, durante o período noturno com menor frequência de irrigação (das 18h às 6h), houve um aumento na concentração de CO₂, possivelmente devido ao fechamento estomático causado pela limitação hídrica. A análise gráfica revelou que a temperatura teve uma influência secundária na dinâmica do CO₂, indicando que o manejo hídrico foi o principal fator regulador neste sistema.

PALAVRAS-CHAVE: Alface. Hídrico. Manejo.

INTRODUCTION

The need to control environmental parameters is undoubtedly one of the main challenges in hydroponic systems that are installed indoors. According to Hebbar et al. (2020), carbon dioxide (CO₂) concentration, together with water availability, are critical elements for the photosynthetic process and, therefore, also for plant growth.

For indoor environments, the use of continuous artificial lighting helps to keep the photosynthetic process active. However, water and nutrients must be available, as the stomatal opening process, responsible for regulating CO₂ intake, is heavily dependent on water supply (Taiz et al., 2017).

According to Olsovska et al., (2016), if significant hydration occurs in plants, the stomata remain open, thus promoting greater CO₂ uptake and, consequently, greater photosynthetic efficiency. However, if there is water limitation, the stomata will close, significantly reducing

CO₂ assimilation and causing gas accumulation in the area (Van Iersel & Gianino, 2017).

Corroborating Graamans et al., (2018), for the regulation of gas dynamics to be complete, there must be an interaction between light intensity and temperature, in addition to humidity and the irrigation cycle, which will impact the productivity and quality of the hydroponic system.

Therefore, the objective of this study is to evaluate the interference of the water cycle on CO₂ concentration dynamics in a hydroponic lettuce crop in a closed environment with continuous artificial lighting.

MATERIALS AND METHODS

The experiment was conducted from March to May 2025 at the Hydraulics and Irrigation Laboratory of the Department of Agricultural Engineering (DENA) at the Federal University of Ceará (UFC), located in the city of Fortaleza (CE), whose geographical coordinates are latitude 3°44'44.9"S, longitude 38°34'53.1"W, altitude 21 meters.

The crop used for analysis was lettuce, which was grown in a NFT hydroponic system in a completely closed environment with continuous artificial lighting.

The hydroponic system measured 70 cm wide, 123 cm long, and 60 cm high. It consisted of six 75 mm PVC pipes, three for red-blue LED lighting and three tubes of the same specifications for white LED lighting, perforated with a distance of 25 cm between the cultivation holes, with four holes per tube, 12 per treatment, totaling 24 cultivation holes in total. The channels were suspended on a 35 mm PVC structure.

The MG811 sensor was used to collect CO₂ data, which was stored on the ThingSpeak server, integrated with the MATLAB[®] platform. The sensor was used in conjunction with the EPS32 microcontroller, which enabled data to be sent via Wi-Fi.

The irrigation management adopted consisted of 15-minute cycles with the pump turned on and 5 minutes turned off, during the period from 6:00 a.m. to 10:00 p.m. At night, three 15-minute irrigations were performed at midnight, 2:00 a.m., and 4:00 a.m.

RESULTS AND DISCUSSION

It should be noted that during periods of intermittent instability (6 a.m. to 6 p.m.), average CO₂ values tended to stabilize at lower levels, which is directly associated with increased photosynthetic activity. This is due to greater stomatal opening favored by water availability, allowing greater CO₂ uptake from the environment.

However, during nighttime periods (after 6 p.m. to 6 a.m.), when there are only three sporadic irrigations, there is an increase in CO₂ concentration, reflecting reduced gas absorption as a result of partial stomatal closure due to lower water availability in the root zone, as shown in Figure 1.

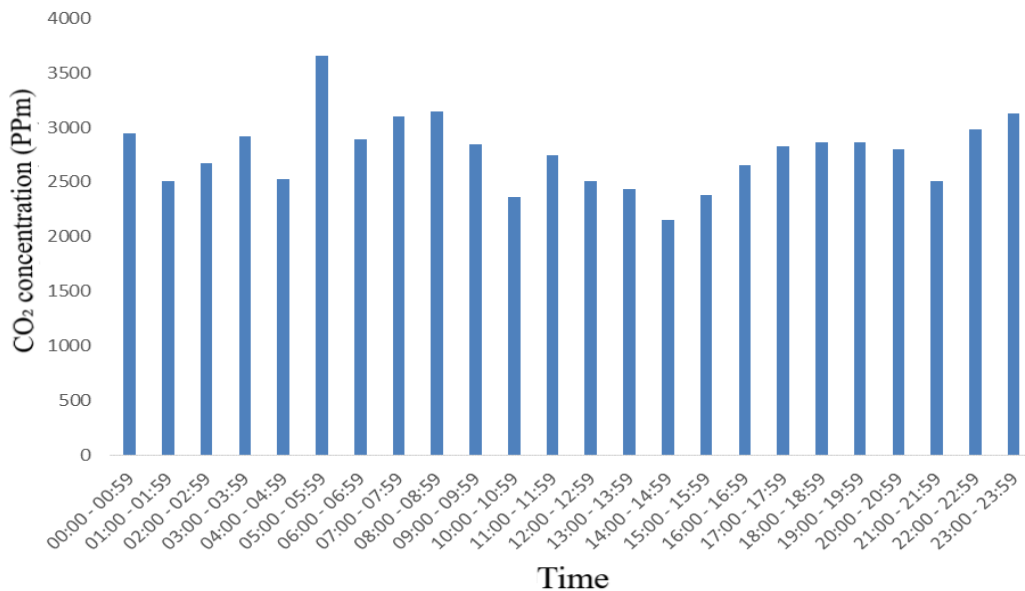


Figure 1. Analysis of CO₂ concentration variation as a function of time in hydroponic cultivation

This behavior reinforces the understanding that, even in environments with continuous artificial lighting, water remains the main factor modulating stomatal activity and gas exchange dynamics (Huang et al., 2024; Oliveira et al., 2023). Therefore, water not only transports nutrients but also directly regulates plant physiology.

The highest CO₂ peaks are observed at times when the temperature is not necessarily at its maximum, but rather associated with the end of irrigation cycles or periods without irrigation, indicating that the water factor plays a more relevant role in controlling stomatal opening and, consequently, in the dynamics of CO₂ in the environment, as shown in Figure 2.

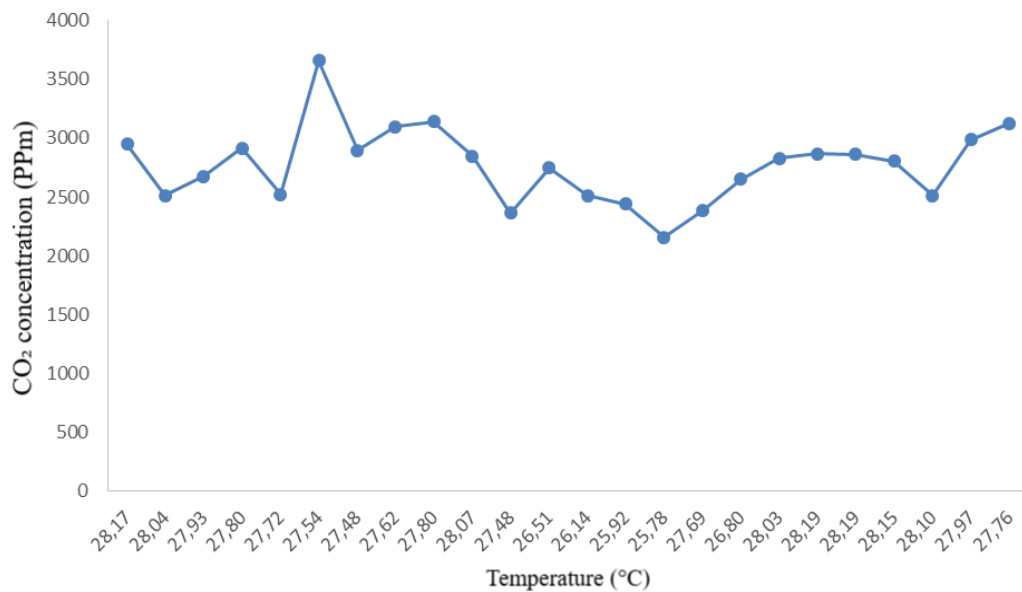


Figure 2. Association between CO₂ concentration and temperature

The most evident fluctuation in CO₂ concentration occurs in the range where there is a sharp drop in temperature to values close to 26.14°C to 25.78°C, indicating possible stomatal closure, resulting in lower CO₂ assimilation by the plant. On the other hand, when the temperature rises to levels above 28°C, a moderate increase in absorption is observed, although this relationship is modulated more directly by the water availability of the system, and not exclusively by temperature.

Adhikari et al., (2024) presented in their study that small variations in the root environment, particularly related to root hydration, promote rapid physiological responses, while thermal effects become less beneficial in controlled growing environments. They also found that in hydroponic lettuce crops, CO₂ dynamics are more sensitive to variations in water availability than to small temperature gradients, especially in controlled environments.

CONCLUSIONS

However, it can be concluded that water availability (affected by irrigation management) was the factor responsible for balancing CO₂ concentration in hydroponic lettuce cultivation under continuous artificial lighting. During periods of intermittent and regular irrigation, less CO₂ accumulation was observed in the environment, evidencing greater photosynthetic efficiency associated with greater stomatal opening. On the other hand, during periods with

lower water supply, there was a significant increase in CO₂ concentration, indicating a physiological response of plants to water limitation.

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