Analysis and improvement of CO2 enrichment performance in greenhouse production based on the simulations of microclimate, photosynthetic distribution and energy utilization efficiency

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(温室における微気象・光合成の分布とエネルギー利用効率のシミュレーションに基づく CO_2 施用効果の解析と改善)

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Thesis Summary

Research background and purpose

Protected cultivation is an important solution for achieving sustainable agriculture and ensuring food security. Compared with open field cultivation, it could shield crops against unfavorable conditions in the open fields and conduct a comprehensive adjustment of multiply environmental parameters (such as temperature, humidity, air current, lighting intensity, and CO_2 concentration) affecting the crop photosynthesis. However, such environmental control is a highly energy-consuming process, part of which, CO_2 enrichment, requires direct consumption of fossil fuel energy. To achieve sustainable and economical greenhouse management, the performance and energy utilization efficiency of CO_2 enrichment in greenhouses should be understand. This study focused on having a comprehensive analysis of the CO_2 enrichment performance in commercial greenhouse production and proposing more efficient enrichment strategies. The analysis for CO_2 enrichment performance was based on the spatial distribution of greenhouse microclimate parameters, leaf photosynthetic rate, and energy use efficiency.

(1) Performance of current CO_2 enrichment in commercial greenhouses with different geometry features

To get a more efficient usage of CO_2 enrichment in greenhouse production, the performance and problems of current CO_2 enrichment method must be identified. In this section, the performance of the currently used CO_2 enrichment method in different commercial strawberry greenhouses with different length and width was investigated. The spatiotemporal distribution of CO_2 concentration inside greenhouses was simulated using computational fluid dynamics (CFD) model and the leaf photosynthetic rate distribution was also simulated using a combined plant-environment coupled mathematical model group. The result showed that the spatiotemporal distribution of CO_2 and photosynthesis varied significantly depending on the geometry features of the greenhouses. According to the analysis of CO_2 enrichment efficiency (as the ratio of increasing photosynthesis on the cultivation plane to the amount of CO_2 usage), when the average CO_2 concentration in the cultivation plane was approximately 500 μmol mol^{-1} could have the best enrichment efficiency.

**(2) Advantages of crop-localized CO_2 enrichment compared with the conventional entire

enrichment

Different environment control strategies and equipment could significantly differ in control performance and energy usage efficiency. In this section, a recently proposed crop-localized enrichment method ('Local Enrichment') was tested and compared with the conventional overall greenhouse enrichment method ('Entire Enrichment'). The spatial distribution of microclimate parameters was simulated using CFD models; based on the results, the spatial distribution of the crop photosynthetic rate was also simulated using an environment–plant coupled model group. Furthermore, the CO_2 enrichment efficiency was quantitatively analyzed by calculating the changes in the photosynthetic carbon assimilation capacity of the crop canopy in relation to CO_2 usage. Compared with Entire Enrichment, the Local Enrichment method reduced the effects on greenhouse temperature and humidity but increased the average CO_2 concentration inside the canopy by 264 μmol mol^{-1}. As a result, the Local Enrichment increased the average leaf photosynthetic rate inside the canopy by 1.48 μmol m^{-2} s^{-1}. According to CO_2 enrichment efficiency analysis, Local Enrichment demonstrates huge advantages over Entire Enrichment (more than five times higher on average).

(3) Scenario analysis for improving the application of clop-localized enrichment method

CFD provides a s a convenient way to verify different environment control methods without tedious field testing. In this section, the performance of local CO_2 enrichment in larger greenhouses and under ventilated conditions was simulated. The result showed that the Local Enrichment system could be applied to larger greenhouses and improve enrichment efficiency relative to that in a conventional system. In addition, local enrichment can be used under ventilation conditions, which would greatly extend the use period of CO_2 enrichment.