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Simulation of Solar Radiation and Heat Transfer in an Agrivoltaic Multi-level Greenhouse for Enhanced Energy Efficiency and Crop Growth

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Extended Abstract

Multi-level crops cultivation offers a promising solution to address the challenges of urbanization, nutritional security, and sustainable agriculture. Many initiatives however, were never realized due to high initial investment and operation costs and limited knowledge of indoor agricultural practices. Here we propose introducing technologies that will reduce energy consumption making use of solar energy and further reducing labour costs that will certainly change this negative balance. Integrating solar panels into greenhouses can provide renewable off-grid energy source to power the farming facilities. The energy generated from PV panels can be used for lighting, climate control, irrigation, and other operational needs, reducing dependence on conventional energy sources and can benefit from lower operational costs in the long run [1]. However, the feasibility of agrivoltaic greenhouse depends on factors such as the local climate, the available sunlight, initial investment costs, and the specific energy requirements of different crops. Our study focuses on challenges associated with balancing the need for solar energy generation with the need for efficient use of growing space.

Solar radiation simulations (Monte Carlo Ray Tracing model) coupled with the heat transfer numerical models (a three-dimensional CFD model using ANSYS Fluent software) have been developed to examine the parameters affecting solar radiation distribution and microclimates in a multi-level structure. The geometry and dimensions of the model were derived from an operating hydroponic greenhouse located in the central region of Israel. The CFD model was utilized to simulate airflow dynamics using k-ε turbulent model and temperature distribution in the greenhouse using conservation equations for free convection. Plant transpiration rates, assumed to be uniform, were included to the energy equations as constant mass rates. The input parameters were also geographic location, a specific day during the growing season, and meteorological data. The modelling results were validated by experimental measurements conducted in the greenhouse over the last year [2,3] in terms of solar radiation fluxes and inside air temperature. Different PV installation layouts, such as side or center edges of the greenhouse, or different roof patterns, were examined in combination with the optical properties of the covering materials (transparency and diffusion coefficient). Climate control management methods were examined in terms of structural design, ventilation methods, LED lighting power for lower level, and external environmental conditions while considering optimal solar energy generation. The results are the total solar radiation and heat fluxes reaching the PV panels and upper and lower levels of the growing space. It was illustrated that, besides for in the winter, there is enough radiation reaching the upper level of the greenhouse. Nevertheless, the energy generated by the PV panels is not enough to cover entire energy demand for the artificial LED lighting on the bottom level. However, it contributes to the overall sustainability of the greenhouse. Moreover, configurations with central and checkerboard patterns can offer shade to the plants, a requirement that varies depending on the plant variety. Currently, a shade net is employed for shading in summer, but it can't be utilized to generate energy. Our study will serve as a model and will be implemented in different climatic zones of Israel, as well as in other countries and regions.

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