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Modified plastic net-houses as alternative agricultural structures for saving energy and water in hot and sunny regions

A.M. Abdel-Ghany [a, *], I.M. Al-Helal [a], P. Picuno [b], M.R. Shady [a]

[a] Department of Agricultural Engineering, College of Food and Agriculture Sciences, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia
[b] SAFE School, University of Basilicata, Via dell'Ateneo Lucano, n.10, 85100 Potenza, Italy

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ABSTRACT

The transmitted radiation into the conventional net-houses is very low in the early morning and late afternoon that may not fulfill the crop growth requirements. To solve this problem, two types of net-house models (polygon and curved-arch net-houses) were newly designed, each having seven surfaces made up of different net types. The spectral radiative properties of 32 nets were examined and three nets were selected to cover the surfaces of each model. The two designs showed high transmittance in the morning and afternoon, and low at around noon (U shape). The polygon style was scaled-up and an experiential net-house was constructed with a floor area of 28 m^2. An evaporatively-cooled greenhouse with a floor area of 28 m^2 was used for comparison; each floor was planted with 500 potted *Chrysanthemum* plant. The results showed that the PAR and microclimate in the net-house and cooled greenhouse were similar. The net-house reduced water consumption by 13 kg m^{-2} day^{-1} in summer and by 0.94 kg m^{-2} day^{-1} in winter; and reduced electric energy consumption by 0.26 kw-h m^{-2} day^{-1} in summer and by 0.18 kw-h m^{-2} day^{-1} in winter compared to the greenhouse.

1. Introduction

In hot and sunny regions, protected cultivation has become essential for protecting crops from the harsh environment and for enhancing and managing crop production throughout the year. Greenhouses work well in regions with a cold or mild climate; however, in hot and sunny regions overheating of the inside greenhouse air is a frequent problem, which makes it very difficult to grow plants in a greenhouse in summer without efficient cooling systems [1–3]. This problem was initially overcome by employing shade cloths mounted externally on the greenhouse cover to reduce the solar radiation levels and the internal energy of the greenhouse [4–8]. Even though shading is applied to a greenhouse, an efficient and appropriate cooling system is required to reduce the inside air temperature in summer. In addition, forced ventilation that consumes additional power is required. Evaporative cooling methods, which are commonly used in greenhouses, are not well suited for use in the Arabian Peninsula because of the high salinity of water resources [1,3].

In the last decade, plastic film has been increasingly replaced with plastic nets. The so-called net-houses have specific advantages over greenhouses [9] such as: (i) Reducing the solar radiation load as well as the evapo-transpiration and protecting plants from sun spots in summer. (ii) Scattering of solar radiation diffusively allowing plants to receive light from all sides (nets can enhance the transmitted diffuse radiation by 17–170% depending upon the color and structure of the net textures [10]). (iii) Reducing air velocities and wind damage to leaves and fruits. (iv) The possibility of retaining heat for cold protection at night. This is because a perforated net acts as a thermal barrier between the plants and the outside cooled environment at night. Keeping in mind that the transmitted solar radiation intensity into the net-house as well as the spectrum quality of light can be regulated based on the net porosity and its color. Thus, in sunny regions the light intensity inside the net-houses can fulfill the crop growth requirements in summer and winter as well; and the plants are protected from frost in winter and sun spots in summer. (v) The increase of the inside net-house air temperature is much lower than the uncooled greenhouse. (vi) Colored nets can filter out (by reflection) different colors in the visible (PAR) spectrum and they can produce changes in flowering and branching patterns; therefore, plant morphology can be controlled under colored nets according to specific

* Corresponding author.
E-mail addresses: aghany@ksu.edu.sa, amghany@yahoo.com (A.M. Abdel-Ghany).

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requirements [11,12].

Although the total area of plastic net-houses around the world is steadily increasing, little is known about the optimal shape of the structure and the optimal net types used to cover the structure to perform the net-house. Three styles of net-houses are currently used: gable style, curved-arch style and parallelogram style. These structures are usually covered with one type of net (having a certain color, shading power and porosity) [13]. In addition, only few studies have examined the environment inside net-houses (i.e., a conventional structure covered with one type of net). Studies of net-houses include measurement of the microclimate and ventilation rate [14], evaluation of the use of polyethylene sheet tunnels inside a net-house to provide a greenhouse effect in winter [15], thermal modeling of heat transfer in a net-house [16], measurement of the environment and solar radiation transmission to evaluate the radiometric performance of the nets [17], and measurement of the environment, growth rate and productivity of tomato crops [18]. On the other hand, most net-house studies have focused on evaluating the radiative properties of plastic nets [3,11,19–21].

In conventional net-houses (ones covered with one type of net), the transmittance of solar radiation is nearly constant during the day. Under high solar irradiance such as in the Arabian Peninsula nets with low porosities (i.e., with high shading factors) are usually used to cover the net-houses throughout the day and night to strongly reduce the transmitted solar radiation at around noon. As a result, the transmitted radiation inside these houses is very low in the morning and afternoon which may not fulfill crop growth requirements. Consequently, this would significantly reduce the ventilation rate which negatively affects crop growth.

Accordingly, the main objective of this study was to develop different net-house styles, able to enhance the transmission of solar radiation in the morning and in the afternoon; and to strongly reduce the transmission of solar radiation at around noon. In the proposed net-house design, nets with high porosities were used vertically for the sides of the net-house to enhance the radiation and ventilation rate in the crop level. Nets with low porosities were used to cover the upper horizontal or curved surfaces of the net-house to serve at around noon. The newly developed net-house models will be evaluated, based on their transmittance pattern, and the optimum design model with the appropriate covering nets will be scaled-up to construct an experimental net house for environmental and economic evaluation.

2. Materials and methods

2.1. Constructing conventional net-house models

For comparing the transmittance pattern of the proposed designed net-house models (NHMs) with that of the conventional ones, three conventional models (i.e., gable as the one in Fig. 1(a), curved-arch as the one in Fig. 1(b), and parallelogram as the one in Fig. 1(c)) were constructed from wood bars (3 cm × 3 cm cross section); each having 70 cm width, 150 cm length and 70 cm height. The conventional net-house models were covered simultaneously with three types of nets (i.e., white-50, black-50 and green-50) in three consecutive sunny days, one day for each net covering for measuring the conventional models' transmittances. The solar radiative properties of nets used to cover the three conventional models are reported in Ref. [3].

2.2. Constructing the newly developed net-house models (NHMs) for optimization

To achieve the optimum net-house design, six small (~1.0 m

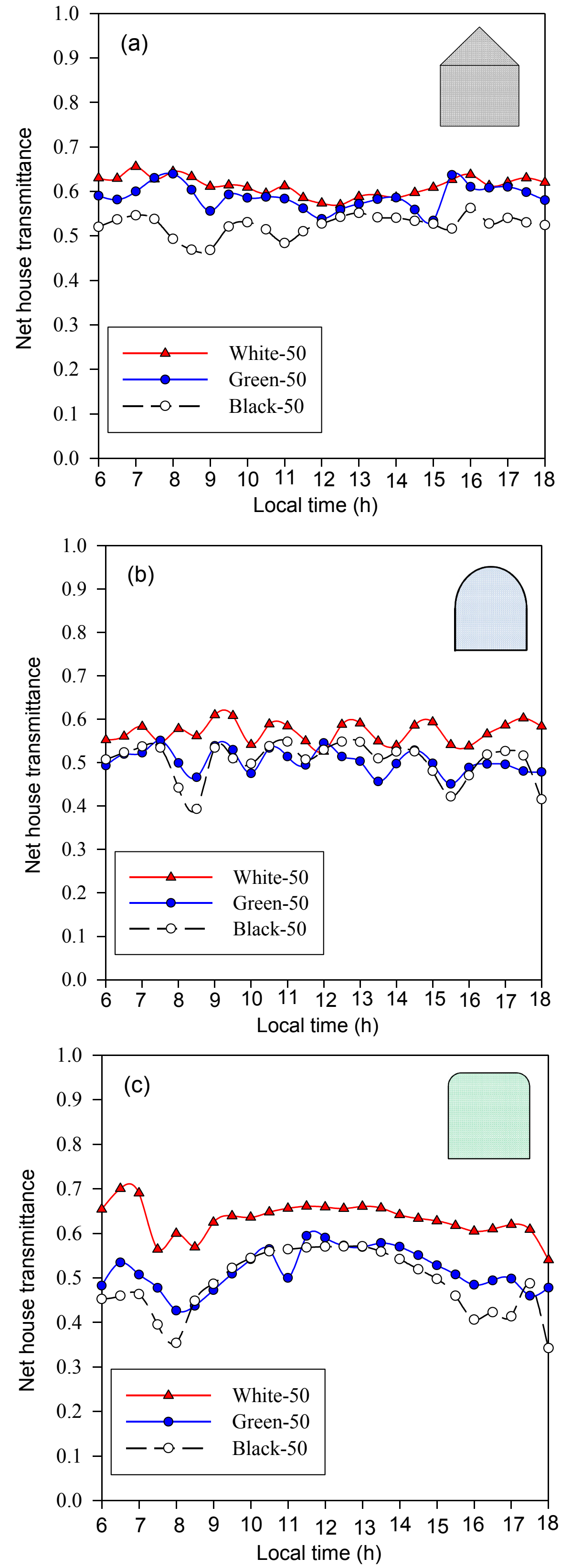

Fig. 1. Transmittance of the conventional net houses to global solar radiation: (a) the gable style, (b) curved arch style, and (c) parallelogram style; all were covered with three plastic nets (March 9–11, 2014).