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Review

# Effects of shading and insect-proof screens on crop microclimate and production: A review of recent advances

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ABSTRACT

Shading and insect-proof screens are widely used in agriculture for passive microclimate control and for insect exclusion. It is an efficient tool for crop production in adverse climatic and environmental condition. As screens are made of a porous material, the protected environment usually interacts with the outside and hence screens provide only moderate microclimatic modifications. Nevertheless, such modifications might be crucial for certain horticultural processes, thus may strongly influence production and quality. Depending on the type of screen, structure configuration, crop and climatic region, recent studies have shown that compared to open field conditions, screens reduce solar radiation and air velocity by about 15–39% and 50–87%, respectively; increase air relative humidity by 2–21%; decrease air temperature and evapotranspiration by 2.3–2.5 °C and 17.4–50% respectively. This paper seeks to review recent advances regarding effects of such screens on microclimate, crop water use and production. Therefore, the ultimate objective of this review is to assist both researchers and growers. For researchers the review provides up-to-date information of the recent studies as well as knowledge gaps that call for future research. For growers and extension service experts this review would assist in choosing the appropriate screen for a specific application, based on the current knowledge.

## 1. Introduction

Netting is becoming a commonly used tool for cultivation. Shading screens/nets can control plant growth by reducing the light intensity and modifying other micro-environmental conditions, e.g., air and soil temperature, air humidity, carbon dioxide ($CO_2$) concentration, air velocity and ventilation rate (Song et al., 2012; Zhao et al., 2012). Moreover, it can decrease water loss (evapotranspiration) from plants and soil and increase $CO_2$ assimilation (Rajkumar et al., 2002). The microclimate modifications, especially the reduction in solar radiation, wind speed and temperature, and the increase in absolute humidity, decrease the evaporative demand, i.e., the dryness of the atmosphere. The lower evaporative demand under shade allows plants to increase stomatal conductance and hence $CO_2$ assimilation compared to crops in the open (Haijun et al., 2015).

Depending on the screen material and its properties, screenhouses are used to achieve various objectives, such as: exclusion of virus-transmitting insects and birds (Möller et al., 2010; Ross and Gill, 1994) and consequently reduced pesticide requirements; sensitive spectral absorption of light for pest control (Antignus et al., 1998); reducing the vulnerability of hail and wind damage (Ilic et al., 2015; Möller et al., 2010; Rajapakse and Shahak, 2007; Shahak, 2008; Stamps, 2009; Tanny and Cohen, 2003; Widmer, 2001); extension of the growing period and delay of fruit ripening; reduction of radiative heat loss and cooling at night (Möller et al., 2010; Teitel et al., 1996); and shading from supra-optimal radiation (Möller et al., 2010; Raveh et al., 2003). Teitel et al. (1996) identified aluminised screen as the most effective in reducing frost damage out of different screens that were tested. The increasing popularity of screenhouses derives mainly from their fulfilling the above purposes at much lower cost of conventional greenhouses.

Photo-selective screens induce modifications in vegetative and fruit attributes. While comparing different coloured nets with same shading factor, researchers revealed that, red and yellow nets kindle the vegetative growth rate and vitality of foliage and cut flower crops, while the blue nets caused dwarfing, and the grey nets enhanced branching and bushiness. Furthermore, pearl nets have the greatest light-scattering capability in the visible range and also absorb light in the ultra-violet (UV) range, thus found to best increase fruit size and yield in fruit tree crops, as well as postharvest quality of fresh produce (Alkalai-Tuvia

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**Nomenclature**

| | |
|---|---|
| AC | ascorbic acid |
| ASA | antioxidant scavenging activity |
| BC | bioactive compounds |
| BES | Besor Experimental Station |
| $C_4$ | $C_4$ carbon fixation |
| CFD | computational fluid dynamics |
| $Chl_{a,b}$ | chlorophyll *a* and *b* (mg. $g^{-1}$) |
| CMV | cucumber mosaic virus |
| ET | evapotranspiration (W. $m^{-2}$) |
| $ET_0$ | reference evapotranspiration (W. $m^{-2}$) |
| $ET_c$ | crop evapotranspiration (W. $m^{-2}$) |
| $F_{mass}$ | fruit mass (g) |
| $g_s$ | stomatal conductance (mmol. $m^{-2}$.$s^{-1}$) |
| GS | green 44%-shading screen |
| $h_{n-a}$ | convective heat transfer coefficient (W. $m^{-2}$. °$C^{-1}$) |
| $H_{sh}$ | higher screenhouse |
| HDPE | high density polyethylene |
| HW | head weight, g |
| IMSL | International Mathematics and Statistics Library |
| IP-1 | pearl insect-proof 24%-shading screen |
| IP-2 | white insect-proof 42%-shading screen |
| IPN | insect-proof nets |
| KSU | King Saud University |
| $L_{sh}$ | lower screenhouse |
| LAI | leaf area index |
| LE | latent heat flux (J.$s^{-1}$. $m^{-2}$) |
| OAAC | odour active aroma compounds |
| PAR | photosynthetically active radiation (μmol. $m^{-2}$.$s^{-1}$) |
| $P_n$ | net photosynthesis (μmol. $m^{-2}$.$s^{-1}$) |
| PP | polypropylene |
| PVY | potato virus Y |
| PWL | postharvest weight loss (%) |
| PY | postharvest yield (%) |
| $Q_{n-a}$ | convective heat exchanges (W) |
| RH | relative humidity |
| SSC | soluble solid concentration (%) |
| TA | titratable acidity |
| TCC | total chlorophyll content (μg. $g^{-1}$) |
| TSS | total soluble solid (%) |
| TUT | Tshwane University of Technology |
| TYLCV | tomato yellow leaf curl virus |
| VPD | vapour pressure deficit (Pa) |
| $Wt_{l,r}$ | leaf and root dry weights (g) |
| Φ | net porosity |
| $\rho_{P,g}$ | global PAR reflectance |

et al., 2014; Goren et al., 2011; Ilic and Fallik, 2017; Kong et al., 2013; Shahak, 2008).

According to the literature, photo-selective shading nets markedly improve the fruit quality (Goren et al., 2011; Kong et al., 2013) and reduce the crop infestation by pests and diseases (Díaz-Pérez, 2014). Besides, coloured nets could reduce light intensity by at least 50% relative to the outside during the summer months, resulting in light intensity levels similar to fall and spring (Ilic and Fallik, 2017; Ilic et al., 2017a).

Different crops might show different growth and quality responses under the same shade nets and the effects can be further modulated by applying shade nets alone or in combination with additional plastic sheet covering (Ilic and Fallik, 2017; Ilic et al., 2015; Milenkovic et al., 2012). Shading screens could be applied alone as shading houses or as additional shading in greenhouses; in the latter they can be deployed either internally (below the roof) or externally (above the roof) depending on the climatic region and crop demands. In arid regions, a disadvantage of internally shaded naturally ventilated greenhouses is that when the screen is fully deployed below the roof, it will decrease the effectiveness of natural ventilation through roof openings. Additionally, shading materials absorb a portion of solar radiation and reemit it again into the greenhouse as heat. As a result, the reduction of the greenhouse air temperature would be smaller than that expected (Abdel-Ghany et al., 2015b).

The goal of this paper is to review the recent advances regarding shade and insect-proof netting effects on microclimate, evapotranspiration and crop production. It also aims at pointing on drawbacks and future prospects regarding the use of screens. In 2013, a review on screenhouse microclimate and evapotranspiration has been published (Tanny, 2013). In 2017, another review paper has surveyed the effect of light quality manipulations on vegetable quality at harvest and post-harvest (Ilic and Fallik, 2017). The present paper, therefore, undertook the mission of updating on recent advances in crop microclimate and water use as well as extending it with relation to overall crop production. Hence, this article has surveyed a range of relevant peer-reviewed papers most of which were published later than 2013.

Table A1 (in Appendix A) presents recent papers (2013 and later) related to screenhouse microclimate and production. The Table shows that during the past years the focus of research was mainly on three issues: (i) The first is a continued effort in exploring the effects of screens on microclimate and water use. The recent studies cover a wider variety of screen types, including coloured screens, which attract attention of growers and researchers. These studies also benefit from advancement in measuring and analyses tools, including Computational fluid dynamics (CFD). Microclimate and water use continue to attract attention due to the environmental issues related to energy savings and global water scarcity. (ii) The expansion of the use of screens to various crops like vegetables, fruit trees and paddy fields, has increased the interest in their properties and effects on the crops and the environment. (iii) Light manipulation by screens, impact produce quality and quantity at both harvest and post-harvest. Consumers require products of higher and higher qualities and research on the effects of screens on such traits is increasing.

The next section (Section 2) discusses structures and cover materials and reviews studies that specifically deal with the interactions between structural traits and microclimate, Section 3 is focused on radiation, Section 4 on airflow, Section 5 on temperature and humidity, Section 6 on evapotranspiration, Section 7 on crop production and quality, Section 8 on insect invasion and Section 9 highlights some drawbacks and future prospects of screenhouses. Main conclusions are presented in Section 10.

## 2. Structures and microclimate

### 2.1. Materials and structures

Shading screen structures could be of different types, such as flat-roof (no sidewalls), tunnel, screenhouse (with sidewalls) and greenhouse shading (external or internal). Insect-proof screenhouses will always consist of roof and sidewalls to provide full protection against insect invasion. Screenhouses are semi-permanent structures with roof and sidewalls usually made of shading or insect-proof porous screens, mounted on metal poles with support cables. Screens can be categorized in different ways such as materials (e.g., HDPE-high density polyethylene, PP-polypropylene, aluminised screen); colour (e.g., black, red and green); shading intensity (e.g., 30%, 50%) and mesh size (e.g., 50-mesh).