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Intelligent greenhouse design decreases water use for evaporative cooling in arid regions

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Background

Production of vegetables for fresh consumption in arid regions usually takes place in greenhouses with evaporative cooling. In Saudi Arabia, as representative example; greenhouses are usually equipped with pad and fan system. The dry climate of the country ensures a large effect of the cooling system. However, evaporative cooling is attained at the expense of large amounts of water, as water use for cooling easily exceeds irrigation water use.

Objective

The current work evaluates the options for reducing water use of pad and fan cooling systems, by improving the design of the greenhouse and the cooling system. This is done through simulation studies, supported by information obtained from greenhouse trials at ESTIDAMAH.

Methods

The Greenhouses

The greenhouse trials were conducted in 2 different greenhouses at ESTIDAMAH research center:
Plastic tunnel covered with polyethylene film (named L)
Venlo type greenhouse covered with glass named (M)
Both greenhouses are equipped with pad and fan system. The fans are placed higher in the M greenhouse compared to the L. The crop grown was round tomato.

Figure 1. View of the greenhouses. The L plastic tunnel from outside (A) and inside (B) and M glass Venlo greenhouse (C and D) where the exhaust fans are placed higher (C).

The Simulation

The dynamic greenhouse climate simulation model KASPRO was used to compute the water use for the pad and fan cooling system. First, the model was validated with the measured climate and water use data for both greenhouses, for the period of the experiment. Then, the model was used in desk studies to compute the effect on water use of the:
temperature of the air extracted by the fans
cover surface to ground ratio of the greenhouse
(cooling) efficiency of the pad wall.

Results

The Venlo (M) greenhouse was proven to be more water efficient than the traditional tunnel (L), achieving a water saving of more than 40 % per unit of produced product as well as in absolute numbers.

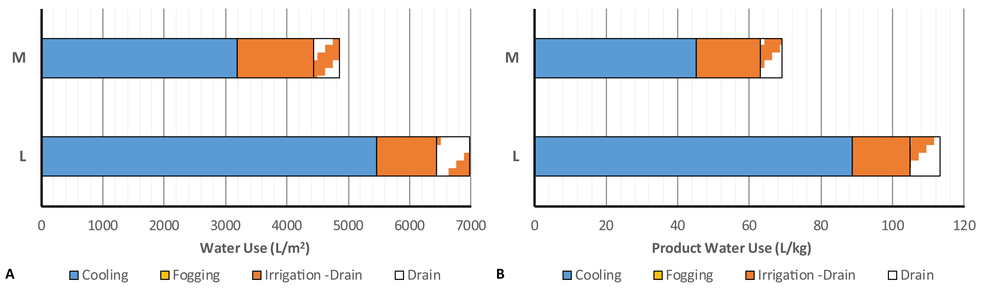

Figure 2. Water use and recovery by each sub-process at each greenhouse system (L plastic tunnel and M Venlo glasshouse) during the experiment, expressed as water amount per greenhouse area (A) and as water amount per fresh tomato weight production (B).

Simulation results

Using the validated greenhouse climate model, several scenarios were simulated. The results indicated that three design elements explain the reported improvement in reducing water use for cooling.

Extracted air temperature

The higher the extracted air temperature, the lower the cooling water use. Greenhouse design should aim to maximize extracted air temperature to reduce cooling water use. Higher placement of exhaust fans increases the extracted air temperature and therefore reduces cooling water use.

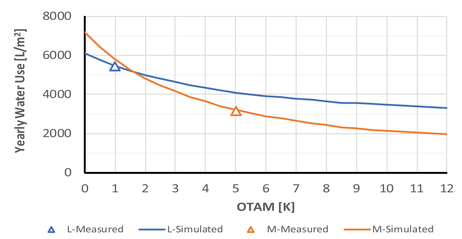

Figure 3. Simulated (lines) and measured (triangles) water use versus Outlet air Temperatures Above Mean greenhouse air temperature (OTAM) in the L (blue) and M (greenhouse).

Cover to ground ratio

The higher the cover to ground ratio, the higher the cooling water use. Big greenhouse complexes are more water efficient than single tunnels or single standing greenhouses with more side walls and therefore higher cover surface to ground ratio.

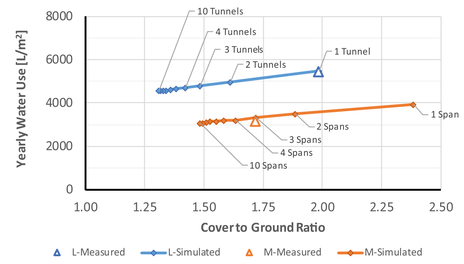

Figure 4. Simulated (closed marks) and measured (open triangles) cooling water use versus cover to ground ratio values corresponding to various number of tunnels (blue) or spans (orange).

Pad wall cooling efficiency

The higher the cooling efficiency of the pad wall the lower the cooling water use.

Well maintained and clean pad-walls increase cooling efficiency and therefore reduce cooling water use.

Figure 5. Simulated (lines) and measured (triangles) cooling water use versus pad wall cooling efficiency values in the L (blue) and M (greenhouse).

Conclusion

The greenhouse design can significantly reduce product water use of tomato in desert conditions.

The extracted air temperature, which is directly related to the placement of the exhaust fans, the pad wall saturation efficiency and the cover to ground ratio of greenhouse complexes have a major influence on cooling water use

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