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Quantifying the trade-off between water and electricity for tomato production in arid environment

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Background

Production of vegetables for fresh consumption in arid regions is usually done in greenhouses fitted with evaporative cooling, which does strain the scarce water resource in those areas so much that [lack of] water frequently becomes the limiting factor. Greenhouses fit with sufficient mechanical cooling capacity (closed/semi-closed greenhouses) not only dispose of the need for evaporative cooling, but also allow for recovery of the water transpired by the crop as condense on the mechanical cooling and dehumidification system. However, such a greenhouse is much more energy demanding in comparison to an evaporatively cooled greenhouse.

Objective

The purpose of this paper is to investigate the trade-off between resources (water and electricity) within a closed greenhouse and evaluate its potential as the ultimate water saving production system.

Methods

All experiments were carried out in identical greenhouse compartments with size 400 m2 at the National Research and Development Center for Sustainable Agriculture (ESTIDAMAH) in Riyadh, Saudi Arabia. The greenhouse is a Venlo type glasshouse, covered with tempered diffuse glass. It is equipped with heating (rail and grow pipes), high pressure fogging system, shading screen, enrichment with liquid CO2, mechanical cooling (air conditioning placed close to the greenhouse cover) and a dehumidification system (condensation on cold surface) that distributes the treated air through five ducts placed under the growing gutters. The crop was round tomato. All water and energy flows were recorded.

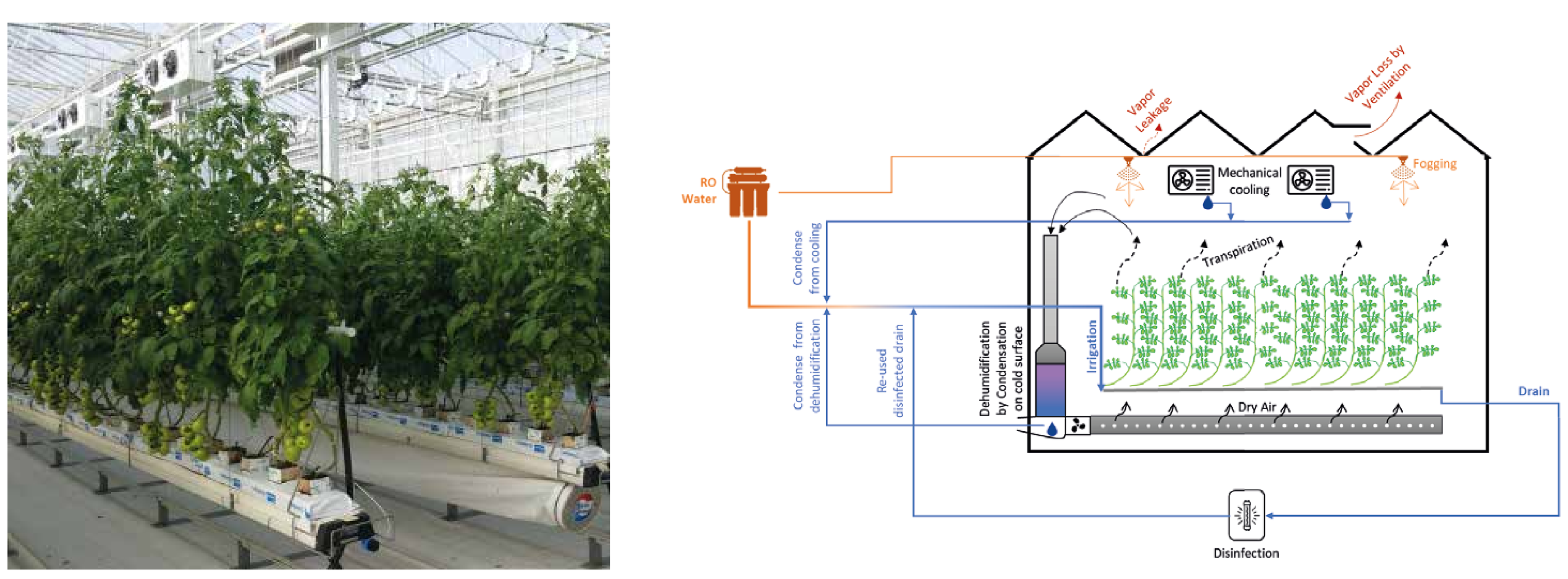

Figure 1. Left: Picture from one of the greenhouses where the experiments were carried out.
Right: Schematic representation of the main water flows in the greenhouse. Water input to the system (shown as orange) consists of the reverse osmosis (RO) water used for irrigation and fogging. Water recovery (shown as blue) consists of the collected drain water and the condense collected on the mechanical cooling and dehumidification units; the recovered water is then used for irrigation. Water losses (indicated as red) consist of the vapor loss via (leakage) ventilation.

Results

- One kilogram of fresh tomato required 4.2L water (average).
- Water use was %15 of the total water supplied to the crop.
- The majority (%85) of the supplied water was recovered and re-used.
- Water recovery was either condense (%70) on the cooling and dehumidification systems or drain (%30).
- Recollecting crop transpiration is the biggest component of water saving.
- Differences in water use between trials were explained by computing the amount of vapor loss via ventilation and leakage ventilation.

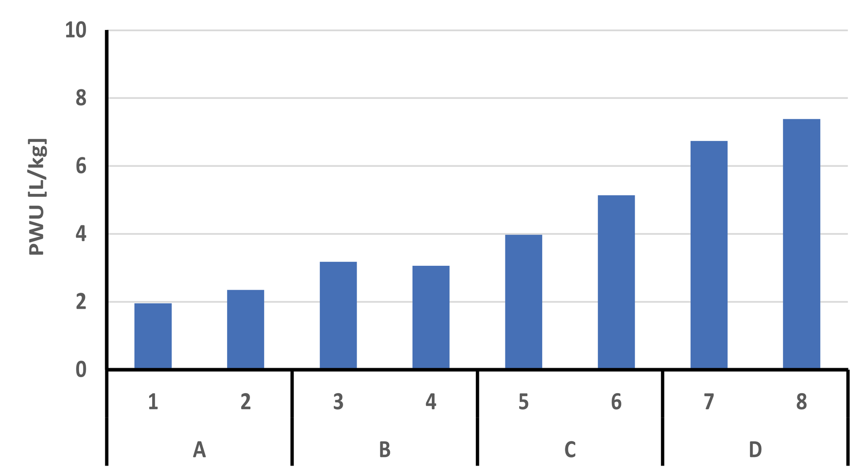

Figure 2. Calculated Product Water Use (PWU) for each greenhouse compartment and trial.

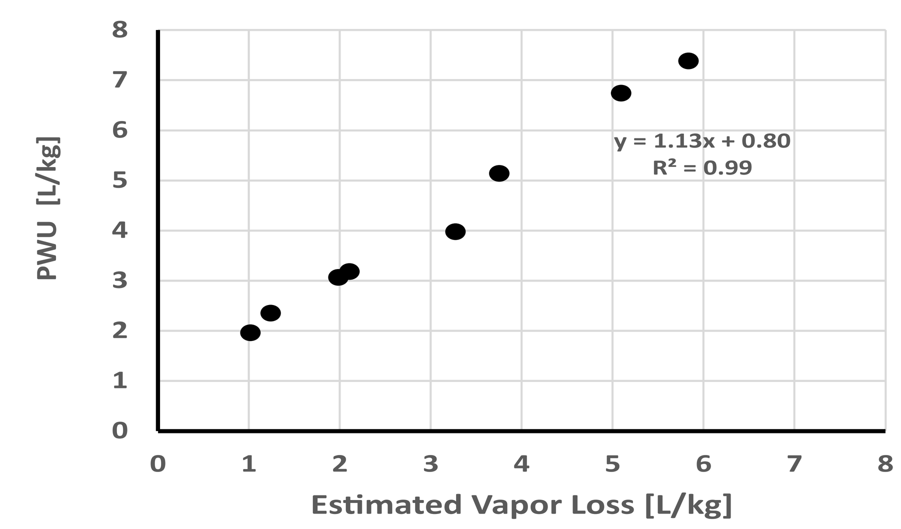

Figure 3. Realized PWU against estimated vapor loss expressed per kg of produced total yield via ventilation and leakage ventilation.

- The achieved water use for tomato production was 40 times lower than commercial practice and 10 times lower than the lowest reported in an evaporatively cooled greenhouse in similar climate conditions.
- This water saving can only be achieved at the expense of energy in the form of electricity required to operate the cooling and dehumidification system. The cooling energy use varied throughout the year from 3 (summer) to 0.4 (winter) kWh.m2-.d1-.
- About 2L of water were recovered for every kWh of electricity spent.
- 1kg fresh tomato was produced in expense of 8kWh electricity (average).

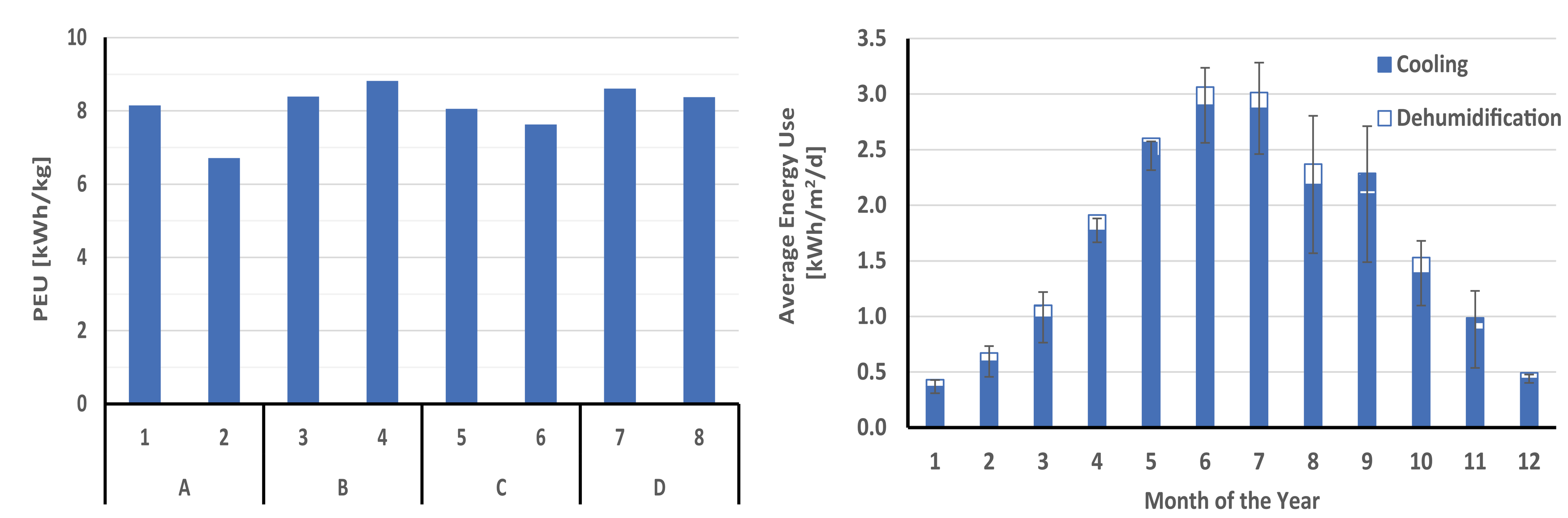

Figure 4. Electricity consumption per kg produced tomato (left) and average daily electricity consumption per month (right). The daily average electricity use is shown separately for cooling (solid bars) and dehumidification (striped bars) purposes.

Discussion

The high electricity use of the closed greenhouse limits its commercial applicability, unless water (saving) becomes extremely valuable.
Using the same amount of electricity, but larger area, can produce 8-4 times more fresh tomatoes in an evaporatively cooled greenhouse with sea water desalinization than in a closed greenhouse.
In the dry arid climate of central Saudi Arabia, only when 10 liters of desalinated water costs more than 1.75 kWh of electricity, the variable costs of a closed greenhouse might drop below the variable costs of a pad and fan greenhouse.
Evaporative cooling becomes less efficient with increasing outside air humidity (e.g. costal areas) while mechanical cooling does not.

Conclusion

After a series of trials in closed greenhouses, under Riyadh climate, the production of 1 kg fresh tomatoes was achieved with average use of 4.2 L of water and 8 kWh of electricity.
The trade-off between water and electricity use is presented and it is the cost of these resources that will predominantly define whether a closed greenhouse would be preferred over an evaporatively cooled greenhouse or not.

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