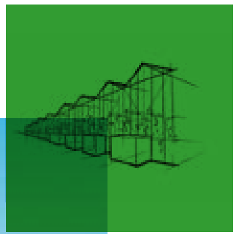
Using less water when growing hydroponically



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Growing on Grodan systems uses significantly less water than conventional production in soil or other substrates.

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Wageningen University
March 2016

Introduction

Water scarcity is one of the global challenges (Glenn *et al.*, 2015). The problem of water scarcity is a growing one. Water use has been growing at more than twice the rate of population increase in the last century. Food and agriculture are the largest consumers of water. As more people put ever increasing demands on limited supplies, the cost and effort to build or even maintain access to water will increase. Water's importance to political and social stability will increase (The Waterproject, 2016).

Question

Is there scientific proof that use of water on soilless systems (e.g. mineral wool substrate) can be less than conventional soil-based systems realising equal or higher kg fresh produce?

Introduction

Figure 1.0
Conventional greenhouse tomato production in soil (A) versus cultivation on mineral wool substrate (B).

The amount of water needed for greenhouse cultivation depends on the crop need for transpiration (main factor is radiation), the water uptake for fresh weight increase, and water losses as a result of run-off, drainage (infiltration) and evaporation from the soil. Water use efficiency (WUE) can be expressed in different ways e.g. referring to total biomass production, or total fruit fresh yield and expressed per unit of water supplied, or per unit water taken up by the crop. Here we express WUE as total fresh marketable product (fruit) per unit of water supplied.
In a substrate culture, it is possible to collect and reuse the drain water, while this is usually not feasible when cultivated in soil (Fig. 1). Therefore, such a system is expected to use less water, in case drain water is indeed collected and reused (so-called recirculation). About 90% (8,500 ha) of the Dutch greenhouse horticulture consists of soilless cultivation. In these greenhouses collection and re-use of drain water is obligatory. That does not result in fully closed systems, as discharge of nutrient solution is sometimes needed (Beerling *et al.*, 2014). Also an NFT (Nutrient Film Technique) system recirculates the water with nutrients and therefore is expected to use less water than open-loop soilless culture or soil-based cultivation . Bradley and Marulana (2001) report that simplified hydroponics technology with recirculation reduces water use for crops by 90% compared to conventional soil-based systems.

Water use efficiency in soil-based and soilless systems

According to the review paper of Putra and Yuliando (2015), traditional techniques in protected agriculture may be highly productive but their relative use of water may be high due to run off and infiltration; thus, the water-use efficiency may be relatively low. Because of a better control of the root environment, soilless cultivation commonly results in higher yields than soil-based cultivation (Engindeniz and Gül, 2009). Soil-based cultivation is likely to use 50–100% more water as a result of water losses from overwatering the soil and evaporation from the soil surface. If we consider yield per unit of water applied, soilless systems may increase yield substantially over soil-based systems. Fandi *et al.* (2008) showed large improvement in water use efficiency when tomatoes were grown on substrate compared to soil, with no big changes in yield or fruit quality. This study was conducted during the 2001 and 2002 growing seasons at the Jordan Valley to evaluate the use of locally available tuff (zeolite substrate; relatively soft vulcanic rock) and sand substrates in comparison with soil for growing tomato using an open soilless culture. This study indicated that open soilless system using tuff as a substrate may be suitable for tomato production without dramatic changes in yield or fruit quality and it saved about 65-70% of water applied by conventional farmers for tomato under plastic house.

In conventional soil-based systems water loss by drainage is substantial. However, providing water in a more precise manner based on tensiometer measurements of water content in the soil, can improve the water use efficiency of a soil-based system. Valenzano *et al.* (2008) reported for tomato that irrigation management practices in two trials on soil using tensiometers allowed to achieve a higher water use efficiency (expressed as g fresh fruit per litre water supplied) than the average obtained in the hydroponic systems (NFT and open-loop mineral wool substrate culture). This result is rarely achieved in common greenhouse farms, due to excessive, and often haphazard, use of water and fertilisers. Between the two hydroponic systems, the closed-loop NFT had a higher WUE than open-loop mineral wool substrate culture.

Just like in soil the water use efficiency in a mineral wool substrate culture also depends on the irrigation strategy. An example of that is presented by Saha *et al.* (2008). These authors compared 6 irrigation strategies, incorporating the electrical conductivity (EC) of the nutrient solution in the mineral wool substrate slab (slab-EC) along with the water content (WC) in the mineral wool substrate slab (slab-WC) as the irrigation decision-making variables. Substantial differences in water use efficiency between the irrigation control strategies were reported (Fig. 2).

Zucchini plants grown in a closed soilless system (cocofibre, perlite and pumice culture) exhibited higher yield (total marketable and fruit number), harvest index, and water-use efficiency compared with those grown in soil (Rouphael *et al.*, 2004). The water use efficiency (i.e. the ratio of fruit dry weight per unit of applied water) was significantly higher by 76% in plants grown in soilless treatments than in soil.

An extreme difference in water use efficiency between conventional and hydroponic growing systems has been reported by Barbosa *et al.* (2015). Water consumption for hydroponic and conventional production of lettuce in Arizona was comparable on an area basis, but when normalized by yield the average was 13 ± 2.7 times less water demand in hydroponic production compared to conventional production. Specifically, hydroponic lettuce production had an estimated water demand of 20 ± 3.8 L kg-1 per year, while conventional lettuce production had an estimated water demand of 250 ± 25 L kg-1 per year (Fig. 3). Note that in this comparison also the difference between open field production (conventional) and greenhouse production (hydroponics) plays an important role. It is well-known that greenhouse cultivation improves water use efficiency compared to open field production (Fig. 4).

Verhaegh *et al.* (1990) showed for fruit vegetables grown on mineral wool with free drainage a water efficiency (ratio between water supply and water uptake) of about 0.70. For soil-grown radish (Korsten and Voogt, 1994) and chrysanthemum (Korsten *et al.*, 1994) this was somewhat lower, 0.60, and 0.52, respectively. Stanghellini (2014) reports a total water use of 6831 and 8632 m3 ha-1 for tomatoes grown on mineral wool either with or without re-use of drain water (closed-loop irrigation). Hence, re-use of drain water resulted in 21% water saving. Commercial yield and quality (oBrix) were the same in both treatments.

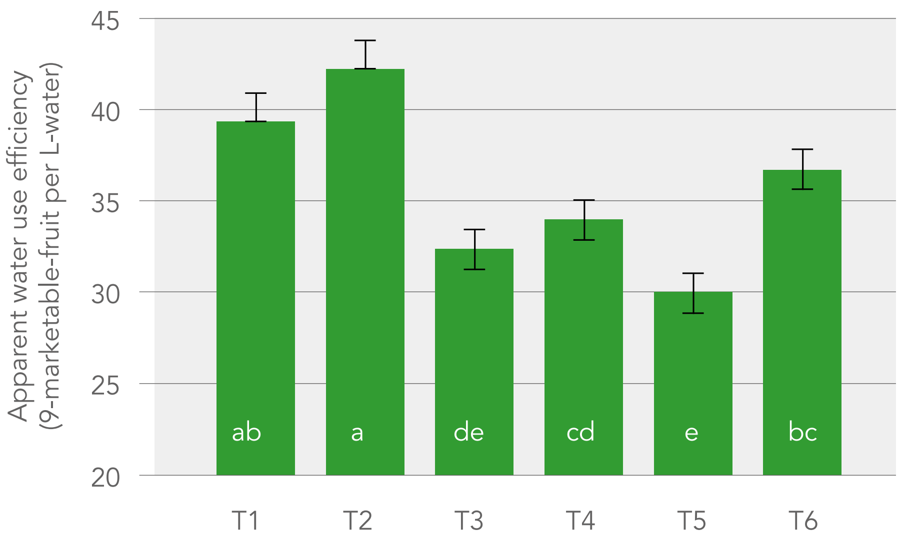

Figure 2.0
Water use efficiency of mineral wool grown greenhouse tomato as influenced by six irrigation control strategies incorporating the electrical conductivity (EC) of the nutrient solution in the mineral wool substrate slab (slab-EC) along with the water content (WC) in the mineral wool substrate slab (slab-WC) as the irrigation decision-making variables: (T1) slab-WC ≤ 70% or slab-EC ≥ 1.4□ normal or more, (T2) slab-WC ≤ 70% or slab-EC ≥ 1.7□ normal or more, (T3) slab-WC ≤ 80% or slab-EC ≥ 1.4□ normal or more, (T4) slab-WC ≤ 80% or slab-EC ≥ 1.7□ normal or more, and (T5) the combined weight loss (WL) 700 g or more and (T6) WL 500 g or more, in which "normal" means the feed solution EC as recommended in the seasonal fertigation schedule for a spring–summer tomato crop. Vertical bars indicate SEs. Columns with the same letter are not significantly different at 5% level of significance (Saha et al., 2008).

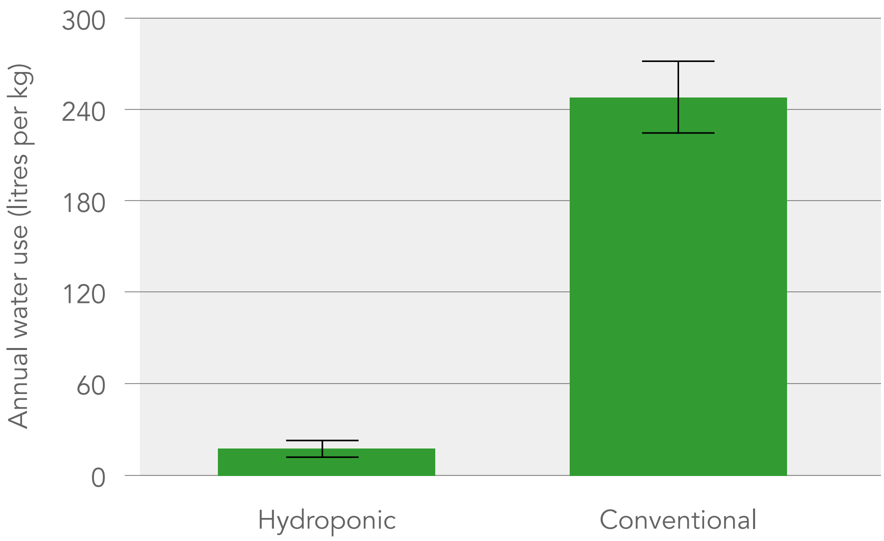

Figure 3.0
Modeled annual water use in liters per kilogram of lettuce grown in southwestern Arizona using hydroponic vs. conventional methods (error bars indicate one standard deviation; Barbosa et al., 2015).

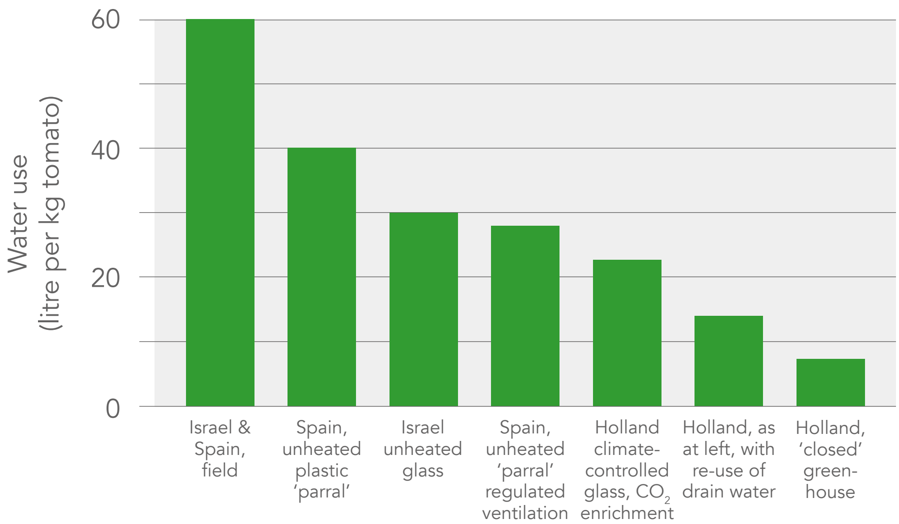

Figure 4.0
Amount of irrigation water required to produce 1 kg of fresh marketable produce in several climates and growing systems (Van Kooten et al., 2008). Last 3 bars (Holland) represent cultivation on mineral wool. "Closed" greenhouse refers to 'no ventilation windows and active cooling system'.

Mean amount of discharge (m^3 ha^{-1} $year^{-1}$)

	Per crop	**Top 20% glasshouses with *lowest* discharge**	**Bottom 20% glasshouses with *highest* discharge**
Cucumber (n=37)	662	133	2.077
Tomato (n=42)	335	52	746
Gerbera (n=33)	1.308	337	2.370

Table 1.0
The yearly amount of discharged nutrient solutions in different crops, with means per crop, means per 20% most and means per 20% least discharging greenhouses (Beerling et al., 2014).

Despite the fact that growers in the Netherlands recirculate the nutrient solution, the discharges of nutrient solution of cucumber, gerbera and tomato (Table 1) are on average about 770 m3 ha-1 year-1, which is circa 10% of the annually overall used nutrient solution (Beerling *et al.*, 2014). The quantity of discharge differs largely between crops, but also between greenhouses with the same cultivation system and crop. For example, for the top 20% tomato growers the discharge is almost zero, whereas for the bottom 20% tomato growers it is 746 m3 ha-1 year-1 (Table 1).

The key factor in recirculation in soilless cultivation systems is the quality of the irrigation water. Growers (and their advisors) tend to avoid risks especially when costs and other consequences for discarding are relatively low. Thus, when there is the slightest doubt about the water quality, the nutrient solution is discarded. However, Beerling *et al.* (2014) estimate that when the tools they developed to tackle obstacles leading to discharge are broadly implemented, discharge and associated emissions will be reduced with approximately 60%. This can be further improved to (almost) 100% by the already known, but not yet broadly implemented solutions to prevent discharge: low sodium supply water, adequate disinfection equipment, and especially reuse of filter back-flush water (Beerling *et al.*, 2014). Hence, soilless cultivation systems can obtain zero water losses, because the nutrient solutions can be recirculated. In soil, precision irrigation can reduce water losses significantly (Voogt *et al.*, 2012), but it will never be zero.

Conclusive summary

In relation to the question on water scarcity and comparison between soilless cultivation and growing in soils, the literature review demonstrates that:

→ Water use in soilless cultivation (substrates like mineral wool and NFT systems) is potentially much lower than in soil-based (conventional) systems. Whether this potential is realised depends on the irrigation strategy, the application of recirculation, and the quality of the irrigation water. Soilless cultivation systems can in principle obtain zero water losses, because the nutrient solutions can be recirculated (Beerling *et al.*, 2014).

→ Soilless cultivation may result in a considerably higher yield compared to cultivation in soil.

→ A reduced water use, and an increased yield for soilless cultivation compared to cultivation in soil, leads to a strongly improved water use efficiency. This means that more (higher production) can be achieved with soilless cultivation in relation to less input (applied amount of water). Or to state it differently, the amount of water needed to produce 1 kg tomato on soil is potentially much higher than the amount needed in soilless cultivation. This difference is often a factor 2 or more.

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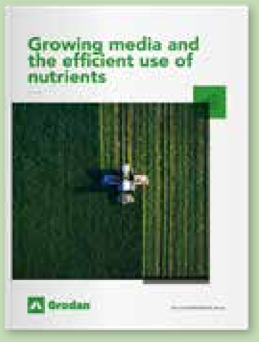

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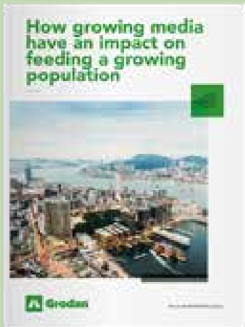

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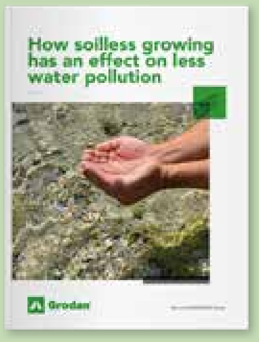

How soilless growing has an effect on less water pollution

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